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ASSESSMENT OF THE SOUTH PACIFIC ALBACORE STOCK

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INTRODUCTION

The albacore, Thunnus alalunga, has been a principal target of tuna fishing in the South Pacific since Japanese longliners began operating near the Solomon Islands in 1952. The Japanese fleet extended eastward and in 1954 some of these vessels began landing albacore, yellowfin tuna, T. albacares, and bigeye tuna, T. obesus, at Pago Pago, American Samoa, under contract to a U.S. cannery there. The fishery grew steadily and was entered by longliners from Taiwan and the Republic of Korea,

Table 1, based at Pago Pago (Table 1). A second U.S. cannery was opened in American Samoa, and other bases for foreign tuna longliners were established in the New Hebrides, Fiji, and Tahiti. Whereas most of the South Pacific albacore catch made by longliners of Korea and Taiwan is taken by vessels based at American Samoa and other foreign ports, the majority of the Japanese catch has always been by Japan-based longliners, and the Japanese eventually withdrew from the Pago Pago base in 1973.

The longline fishery for albacore is carried out over a wide area from about long. 150°E to 120°W and from equatorial waters south to lat. 40°S (Figure 1). Until the 1970's effort was exerted mostly north of lat. 20°S, especially during the first and fourth quarters, but there has been an increase in effort southward in recent years (Table 8). While albacore remain the principal target of longliners based at Pago Pago, yellowfin and bigeye tunas make up a substantial fraction of the landings, especially by Korean vessels since 1971 (Table 2). All of these historical developments are discussed in greater detail by Otsu (1966), Otsu and Sumida (1968), Skillman (1975), and Yoshida (1975).

Since the buildup of fishing effort in the South Pacific during the 1960's, there has been a keen interest among government scientists and the fishing industry in assessing the albacore resource and measuring the effects of fishing on the stock. The first comprehensive assessment was made by Skillman (1975). He estimated total catches, constructed a first-cut abundance index based on the catch per unit effort (CPUE) of American Samoan-based vessels and fit a production model. He concluded the stock was fully harvested, given the prevailing fishing practices, but left open the possibility that yield could be increased by altering the age-specific patterns of fishing mortality.

In this paper we re-evaluate the status of the South Pacific albacore stock, using more complete and reliable catch statistics than were available to Skillman. We construct an improved abundance index and repeat the production model analysis. Finally we briefly examine the prospects of increasing harvests by altering age at first capture. This is done with an age-structured simulation model of the albacore stock.

Catch Statistics

Estimates of the catch of South Pacific albacore by Japanese longliners are available from the beginning of fishing in 1952. Sample logbook statistics are used to estimate the total catch in number of fish. Estimates of the average weight per fish are obtained by sampling the landings. These two factors are multiplied and summed over time-area strata to produce total yield figures for each year. Tonnage estimates used in this paper were provided by S. Ueyanagi of the Far Seas Fisheries Research Laboratory, Shimizu, Japan.



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The catch statistics for longliners from Taiwan are compiled in a similar fashion and have been published annually since 1967. Catch data for earlier years, 1963 through 1966, were provided for this analysis by R. T. Yang of National Taiwan University. Until 1978 the Taiwan government did not determine the size composition of tuna catches, and average weight figures used in the official Taiwan statistics are based on "eye ball" assessments of weight made as the longlines are hauled. For this reason, we constructed our own estimates of total tonnage. We multiplied the published catch in numbers in each 5° square-month stratum by average weights of albacore caught by vessels from Taiwan in that stratum and measured by biological technicians at the landing sites in Pago Pago.

In the case of Korea the only government statistics available to us were the published longline data covering 1966-70, giving sample catch in number of fish and associated nominal effort. We did not use these statistics. Instead, we estimated the annual Korean albacore catches as the product of two factors: a) the sum of the South Pacific albacore catch by longliners of Japan and Taiwan (as estimated above), and b) the estimated ratio of Korean catches to the combined catches of Japan and Taiwan, as derived from the statistics of Skillman (1975).

The estimated total catches of South Pacific albacore by Japan, Taiwan, and Korea are given in Table 3. The catch by other nations includes small quantities landed by longliners in Fiji and by trollers in Chile and New Zealand.

The catch statistics presented above for Japan and Taiwan are based on the sampling of vessel logbooks (Korea has a similar system). Besides these data sources, there has been since 1962 a separate system of logbook statistics for those vessels based at American Samoa. Data on the numbers of hooks fished and resulting catch by species (number of fish) for each day of fishing, along with fishing positions, are obtained from 80%-90% of the vessels. These statistics are collected by the Office of Marine Resources in Pago Pago, and copies are processed by the NMFS Honolulu Laboratory. In addition, NMFS maintains files of landings statistics from the Starkist and Van Camp tuna canneries in Pago Pago. These give the tonnage of tunas and other species landed by the longliners, number of trips, trip length, and other data. Tables 2 and 4 present some of these statistics.

Table 4

Trends in Catch and Nominal Effort

Table 3 shows that the total albacore catch rose to high levels in the first decade of the fishery and has fluctuated around an average annual catch of about 36,000 metric tons (MT) since 1962. The catch peaked in 1973 when 49,000 MT were taken. Trends in nominal effort are best indicated by the data in Table 4, which show the growth in the total number of trips and days fished per trip for vessels based at Pago Pago. Total days fished reached a peak in 1973 and then dropped sharply after the fuel crisis forced the withdrawal or inactivity of many longliners beginning in mid-1974.

Size Composition

Information on the size composition of South Pacific albacore catches is available from two sources. The Japanese have sampled their catches and determined fork-length distributions since the 1950's. On a much larger scale, NMFS established a biological sampling program at Pago Pago in 1962, and gathered data on sex, fork length, and weight of albacore landed by vessels of Japan, Korea, and Taiwan. The time and position of capture were estimated for each sample. Since 1970 sex and weight determinations have been discontinued due to changes in unloading procedures at the canneries, but length-frequency data are still gathered.

In this report we discuss only the NMFS data. This has been treated extensively by Otsu and Sumida (1968) and Yoshida (1975). The size composition of South Pacific albacore varies markedly between latitudes and sex (Figures 2 and 3). Variation between longitudes and seasons is not so significant. Table 5 shows mean weights and fork lengths of males and females in 5° bands of latitude from the equator to lat. 45°S. North of lat. 30°S males are consistently larger than females and the difference is especially pronounced at the mid-latitudes of lat. 15°-25°S where the mean size of both sexes is greatest. In both sexes, average size increases going southward from the equator until about lat. 25°S, and then declines sharply further south.

The size composition of catches also varies with latitude. Figure 3, with sexes combined, shows that the catch north of lat. 25°S is composed almost entirely of fish larger than 80 cm, and that the fork length distributions are unimodal. Figure 4, taken from Yoshida (1975),

gives latitudinal distributions of fork length separated by sex, and shows this even more clearly. The variability within these unimodal distributions is wholly consistent with the expected variation of size at age for a single cohort as predicted by stochastic versions of the von Bertalanffy growth model, particularly if we assume South Pacific albacore grow to the same maximum sizes as their North Pacific counterparts. The proportion of very large albacore (>110 cm fork length) in South Pacific catches seems to be somewhat less than in the North Pacific, but this may be due to differences in availability.

South of lat. 25°S the size composition of albacore catches changes dramatically, with progressively smaller fish appearing in samples along with the large ones found further north. Either these younger albacore (less than about 5 years) are virtually absent north of lat. 25°S or they are simply unavailable to the longline gear in this region.

In the jig fishery for South Pacific albacore off New Zealand fish range from 45 to 100 cm with 2-4 year old fish predominating (Habib and Cade 1978). Off of Chile, the small catch by trollers consists of fish over a similar size range, with 4-year olds appearing most frequently (Yoshida and Otsu 1963).

Figure 5 and Tables 6 and 7 show the changes in size composition and mean size in the catches since 1962. [All the composite frequency distributions are weighted by total catches in the substrata.] There was no significant change in size composition until the late 1960's, when expansion of effort south of lat. 20°S (Table 8) brought more smaller fish into the catch. In 1973 and 1974 there was a dramatic

Fig. 5
Tables 6,7

Table 8

shift towards smaller albacore in the catch, but the larger fish prevailed again in 1975 and 1976 (Figure 5).

Index of Abundance

We constructed an annual index of abundance for albacore within a specified stock index region based on an average of standardized indices for each group of longliners based at American Samoa. The index for each class (nationality) of vessels was computed from

$$U_i = \frac{\sum_{k=1}^{l_i} \sum_{j=1}^{m_{ik}} \frac{C_{ijk} A_{ijk}}{f_{ijk} p_{ijk}}}{\sum_{k=1}^{l_i} m_{ik}}$$

where U_i = index of abundance in year i in the defined index region

C_{ijk} = catch in the j^{th} fishing zone and k^{th} fishing season during year i

f_{ijk} = associated nominal effort (number of hooks)

A_{ijk} = area of the j^{th} fishing zone relative to a standard zone

p_{ijk} = ratio of the average abundance of albacore in the $(j, k)^{\text{th}}$ cell during year i to the average abundance in the entire index region during year i

l_i = actual number of seasons in which fishing occurred in year i

m_{ik} = actual number of fishing zones in which effort was exerted during the k^{th} fishing season of year i

All elements of U_i are observed except for p_{ijk} . Let n_i denote the total number of fishing zones in the stock region and r_i be the total number of potential fishing seasons. Then for years when the time-space coverage of the index area by the fleet is complete, $\ell_i = r_i$ and $m_{ik} = n_i$ for all i and k and

$$\hat{p}_{ijk} = \frac{\left(\frac{C_{ijk} A_{ijk}}{f_{ijk}} \right)}{\sum_{k=1}^{\ell_i} \left(\frac{m_{ik}}{\sum_{j=1}^{\ell_i} \frac{C_{ijk} A_{ijk}}{f_{ijk}}} \right) n_i} \cdot \frac{1}{m_{ik} \cdot \ell_i}.$$

In this event U_i reduces to the ordinary average-of-ratios catch per unit effort statistic, except that the differences in area of fishing zones are taken into account. Of course, when $\ell_i < r_i$ and/or $m_{ik} < n_i$ for some i , then $\hat{p}_{ijk}$ will be biased unless the population is distributed uniformly in time and space or fishing zones and seasons are chosen at random. These conditions are unlikely at best. To circumvent these difficulties Honma (1974) invokes the assumption that the temporal and spatial distribution of the stock in the index region is constant each year, i.e., $p_{ijk} = p_{jk}$ for all i , and suggests estimating the p_{jk} 's using data from "standard" years when coverage was relatively complete. Supposing there are a_{jk} standard years when the $(jk)^{th}$ stratum was fished, we estimated the average p_{jk} for that stratum by

$$\hat{p}_{jk} = \frac{1}{a_{jk}} \sum_{i=1}^{a_{jk}} \hat{p}_{ijk} / a_{jk}$$

where $\hat{p}_{ijk}$ is as given above.

In applying this procedure to South Pacific albacore we used the logbook data for American Samoa-based longliners from Japan, Korea, and Taiwan. The boundaries of the stock index area were set at lat. 0° to 35° S and long. 160° E to 115° W (Figure 1). Fishing seasons and zones were defined as quarters of the year and areas of 5° lat. x 5° long.

Before the p_{jk} 's and the abundance indices were computed, the catches in each stratum were converted from numbers of albacore to weight of albacore by applying detailed average weight statistics derived from the Pago Pago sampling. Separate average weight estimates were usually available by nation, year, quarter, latitude (5° bands) and longitude (10° bands). In cases where corresponding average weight data were not available for a catch in a given stratum, an average figure for the appropriate latitude was substituted.

Estimates of the p_{jk} 's were computed using the nominal effort and catch-in-weight statistics of both Taiwan and Korea over the standard years 1967 through 1977, when relatively full coverage of the index region was achieved. In each case, p_{jk} were estimated only for strata fished at least five times during the period of standard years (i.e., $a_{jk} \geq 5$). Further, only those cells with $a_{jk} \geq 5$ were included in the subsequent estimation of the stock abundance indices.

Abundance indices, based on p_{jk} estimates from Taiwan data, were computed for Japan, Taiwan, and Korea. (Indices using Korean p_{jk} 's were not substantially different.) The indices for Taiwan and Korea were then standardized to the Japanese index following a fishing power analysis (Table 9). The fishing power analysis employed indices over the 1966-72 period.

Table 10
Fig. 6

After the standardization, indices for each nationality were averaged into a single index. This index is given in Table 10 and Figure 6. The index has been scaled to the Japanese catch rates for 1962 in kg/100 hooks. Figure 6 also shows an index of abundance based on published and unpublished Japanese longline data from 1952 through 1976, using the same p_{jk} as with the American Samoa data. This index is based on Japan-based as well as the Pago Pago-based vessels (Japanese vessels were absent from American Samoa beginning with 1973), and was standardized to the composite American Samoa index. Both the composite index based on American Samoa logbook data and this Japanese index show an apparent decline in abundance since the early 1960's. But the index derived from the unpublished Japanese statistics does not conform to our expectations during the first decade of the fishery when catch rose from nothing to nearly 40,000 MT. Whether this reflects inadequacies in the indexing procedure, biases in the basic data or oversimplified expectations remains to be determined. For the purposes of our production model analysis we will assume the composite index from 1962 to 1977 truly reflects a decline in average abundance over this period.

Estimating Effective Effort

The total effective effort on South Pacific albacore was estimated each year from 1962 to 1977 by dividing the composite index of abundance into the estimated total catch. Results are given in Table 10 and plotted in Figure 6, with units standardized in terms of effort by Japanese vessels based at Pago Pago in 1972.

Production Model

A production model was fit to the total catch statistics and effective effort measure (Table 10) using Fox's PRODFIT program (Fox 1975). Equilibrium conditions were approximated by smoothing the effective effort over 1-, 2-, 3-, or 4-year periods. The model's shape parameter, m , was both fixed at 2.0 (Schaefer form) and allowed to vary as one of the estimated parameters. Results are given in Table 11. It is clear from Figure 7 that the Schaefer model would be inappropriate. The remaining results, for m variable, indicate an MSY between 33,000 and 36,000 MT. The predicted optimum effective effort levels range from 60×10^6 hooks to 389×10^6 hooks, or 2.2 to 14.4 times the 1962 effort and 0.31 to 2.0 times the 1977 effective effort. The low (E_{opt}/E_{77}) figure of 0.31 is based on a 1-year smoothing, so is perhaps less reasonable than the other cases. Still, with both 2- and 4-year effort averaging, the analysis predicts that optimum effort would require a cutback of nearly 40% from the 1977 level. Figure 8 shows the equilibrium yield-effort curve for the 3-year averaging, and Figure 9 gives the result for 2-year smoothing. Both yield curves are fairly flat over a broad range of effort and predict similar catches for effort levels in the neighborhood of recently experienced ones. According to these production models, virtually no increase in yield can be expected to accompany an expansion of effort above the 1977 level, and in fact an average yield nearly equal to the MSY could be achieved at half the 1977 effort.

In 1975 Skillman presented a production model for South Pacific albacore, based on unadjusted ratio-of-average catch per hook statistics of Japanese longliners based at Pago Pago and on total catch statistics from the Asian Tuna Conference proceedings and other sources. His best estimate of MSY was about 35,000 MT at an effort roughly 4.5 times the 1962 effort. The variability in Skillman's data also left some doubt as to the shape of the production curve at high effort levels.

Effects of Age at First Capture on MSY Under Different Stock-Recruitment Models

In our production model results there is some suggestion that recruitment to the South Pacific albacore stock may be fairly independent of the spawning stock size. We estimated this constant recruitment level by applying the approach of Suda (1970) to the estimated annual total catch in number of fish and the associated effective effort statistics, again smoothed over 3-year periods to approximate equilibrium conditions. Using a nonlinear regression procedure, we fitted the model

$$\ln(C_1/f_1) = \ln(qR) - \ln(M + q f_1)$$

where C_1 = annual catch in number of albacore

f_1 = associated effective effort (smoothed)

q = catchability coefficient

R = number of fish recruited to exploited stock

M = natural mortality rate

In this model, the same estimate of R results for all guesses of M ; and estimates of q are directly proportional to the M value. We fixed M at 0.4, and the resulting estimates of R and q were 2.54×10^6 fish and 1.875×10^{-8} /hook. The fitted model is shown in Figure 10. Assuming the recruitment estimate corresponds to fish at about 5 years of age (85 cm fork length), the estimated number of recruits at an age of 2 years is 8.43×10^6 fish.

An age-structured simulation model was constructed to study the response of maximum sustainable yield of the albacore stock to changes in age at first capture under a variety of stock-recruitment hypotheses. Knife-edge recruitment was assumed. The natural mortality rate was assumed constant at 0.4 year^{-1} . An age-length model for North Pacific albacore was used in the absence of such a model for the South Pacific stock ($L(t) = 135.6 (1 - \exp(-0.17(t + 0.87)))$), where L is fork length and t is age in years. Parameters of the length-weight relationship were estimated from Pago Pago sample statistics; the resulting equation was $W = 1.681 \times 10^{-6} \times L^{3.059}$, where weight is in kilograms and fork length is in centimeters.

The stock-recruitment hypotheses displayed in Figure 11 were studied. The equation of this model is

$$R = R_{\max} \left(\frac{S}{S_{\max}} \right)^{\beta}$$

where $S_{\max}$ and $S_{\max}$ are upper limits on recruitment (R) and spawning biomass (S). We set $R_{\max} = 8.43 \times 10^6$ fish so that with $\beta = 0$,

$R = 8.43 \times 10^6$ fish (constant). $S_{\max}$ was determined as the biomass of spawning stock in the absence of fishing when $R = R_{\max}$. Assuming fish above 5 years old are members of the spawning stock, $S_{\max} = 1.33 \times 10^5$ MT.

With this set of parameters the maximum sustainable yield was determined for combinations of $\beta(0, 0.15, 0.32, 0.51)$ and age at first capture (2 years, 3 years, 4 years, 5 years, 6 years, 7 years). Results are given in Figure 12. Under the constant recruitment hypothesis, the simulation model computes a maximum sustainable yield of 37,800 MT, corresponding to an age at first capture of 4 years. However, only slight increase in potential yield would result from lowering age at first capture from 5 years to 4 years. Under the more conservative stock-recruitment hypotheses, the yield potentials are reduced substantially and maximum sustainable yield is achieved at progressively higher ages at first capture. We also ran the model with $M = 0.2$ and with appropriately adjusted $S_{\max}$ and $R_{\max}$. In this case the dome in the constant-recruitment yield curve disappeared and MSY was an increasing function of age at first capture (over the range of 2-6 years) for all stock recruitment hypotheses.

Future Studies

The production model analysis is intended to give no more than a rough idea of the status of the South Pacific albacore stock. As a guide for fishery management policy the analysis suggests that expansion of nominal longline effort should not be encouraged (as far as albacore

catches are concerned), and in fact that substantial economic benefits might result from a cutback of effort. It would be interesting and useful to study the economics of the fleets based at Pago Pago, and to try to forecast the expected effort levels under a variety of economic conditions.

On the biological side, there are several tasks needing attention. First, there is an abundance of size composition data, so the possibility of doing a cohort analysis should be explored. A cohort analysis is likely to be difficult because relatively few age groups are found in the catch and there is no clear separation of length frequency modes for most of the catch. If a cohort analysis is attempted, it should be done by sex, and sex composition will have to be estimated for catches since 1970.

- The simulation model studies could be expanded, exploring more complicated hypotheses with respect to age-specific rates of natural mortality and catchability. An investigation of the robustness of the production model could be part of this.

- A detailed study of relative population density by time and area should be completed. Indices of abundance by size-class should be constructed, and forecasting models using such indices should be attempted.

- The possibility of tagging 2- and 3-year old albacore in New Zealand waters should be evaluated, so that hypotheses on the interdependence of the surface and longline fishery can be tested and so that growth rates and migration patterns can be estimated.

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Table 1.--Number of longline vessels based at Pago Pago, American Samoa, by nationality, 1954-76.

Year	Number of vessels				Total
	Japan	Taiwan	Korea	Undetermined	
1954	17	--	--	1	18
1955	50	--	--	--	50
1956	56	--	--	--	56
1957	61	--	--	1	62
1958	76	--	2	1	79
1959	64	--	4	1	69
1960	60	--	3	1	64
1961	55	--	2	1	58
1962	79	--	5	1	85
1963	117	--	10	1	128
1964	94	11	16	--	121
1965	101	23	33	--	157
1966	79	76	55	--	210
1967	62	128	69	--	259
1968	39	110	85	--	234
1969	18	71	76	--	165
1970	9	115	81	--	205
1971	4	124	90	--	218
1972	2	135	95	--	232
1973	--	172	172	--	344
1974	--	149	171	--	320
1975	--	77	135	--	212
1976	--	93	119	--	212

Table 2.--Landings of albacore (round weight, kg) and yellowfin and bigeye tunas (gilled and gutted, kg) at American Samoa by longliners from Japan, Korea, and Taiwan.

Year	Nation	Albacore	Yellowfin tuna	Bigeye tuna
1954	Japan	349,147	602,546	26,556
	Korea	--	--	--
	Taiwan	--	--	--
1955	Japan	2,109,792	2,260,364	24,181
	Korea	--	--	--
	Taiwan	--	--	--
1956	Japan	3,706,218	2,107,367	215,694
	Korea	--	--	--
	Taiwan	--	--	--
1957	Japan	6,003,530	1,577,288	310,425
	Korea	--	--	--
	Taiwan	--	--	--
1958	Japan	9,784,216	2,412,330	455,112
	Korea	145,974	70,338	17,818
	Taiwan	--	--	--
1959	Japan	9,874,443	1,705,524	422,299
	Korea	456,427	67,350	24,396
	Taiwan	--	--	--
1960	Japan	10,581,094	1,046,692	196,497
	Korea	609,897	81,976	49,567
	Taiwan	--	--	--
1961	Japan	9,225,419	1,230,710	131,197
	Korea	330,047	46,311	9,100
	Taiwan	--	--	--
1962	Japan	12,605,012	1,348,594	518,110
	Korea	634,535	46,658	26,104
	Taiwan	--	--	--
1963	Japan	12,669,394	1,819,131	1,310,142
	Korea	1,460,533	251,672	241,966
	Taiwan	--	--	--
1964	Japan	8,064,088	1,869,650	1,137,607
	Korea	1,767,730	400,476	358,912
	Taiwan	556,279	110,510	48,093
1965	Japan	9,506,437	2,398,729	1,269,411
	Korea	4,344,663	1,429,556	1,302,985
	Taiwan	1,607,648	647,633	360,810
1966	Japan	8,898,816	2,407,009	1,339,728
	Korea	9,116,649	2,019,914	2,268,187
	Taiwan	7,472,107	2,114,768	918,053
1967	Japan	7,477,506	1,124,017	994,319
	Korea	9,699,115	2,070,612	2,699,328
	Taiwan	11,133,742	2,131,791	1,846,787
1968	Japan	3,155,537	1,052,467	274,966
	Korea	6,176,349	3,045,761	1,273,197
	Taiwan	8,090,622	3,238,997	1,221,084
1969	Japan	1,570,750	649,830	80,584
	Korea	10,181,956	4,912,826	1,812,130
	Taiwan	6,977,831	2,576,833	1,327,978
1970	Japan	956,631	225,756	6,242
	Korea	11,942,262	3,663,516	1,321,666
	Taiwan	10,981,609	3,808,017	1,646,830
1971	Japan	379,523	75,240	84
	Korea	9,952,463	4,647,388	945,882
	Taiwan	11,861,105	3,844,595	1,112,017
1972	Japan	59,710	54,832	--
	Korea	9,854,751	6,685,235	1,138,297
	Taiwan	10,253,178	6,036,794	2,001,947
1973	Japan	--	--	--
	Korea	16,764,572	6,660,751	2,527,801
	Taiwan	13,383,806	3,819,636	1,968,300
1974	Japan	--	--	--
	Korea	6,837,993	5,193,551	2,138,182
	Taiwan	7,803,417	2,084,428	1,266,750
1975	Japan	--	--	--
	Korea	4,360,973	4,604,442	1,545,420
	Taiwan	3,478,611	1,537,972	803,607
1976	Japan	--	--	--
	Korea	8,509,220	4,885,548	2,953,224
	Taiwan	6,044,421	1,248,680	562,569

Table 3.--Estimated total catches of South Pacific albacore, 1952-77.

Column	1	2	3	4	5	6	7
Year	Japan	Taiwan	Japan and Taiwan	R	Korea	Other	Total
1952	210	--	210	--	--	--	210
1953	1,091	--	1,091	--	--	--	1,091
1954	10,200	--	10,200	--	--	--	10,200
1955	8,420	--	8,420	--	--	--	8,420
1956	6,220	--	6,220	--	--	--	6,220
1957	9,764	--	9,764	--	--	--	9,764
1958	21,558	--	21,558	--	146	--	21,704
1959	19,344	--	19,344	--	456	--	19,800
1960	23,756	--	23,756	--	610	--	24,366
1961	25,628	--	25,628	--	330	--	25,958
1962	38,880	0	38,880	0.0154	599	--	39,479
1963	33,500	608	34,108	0.0400	1,367	--	35,475
1964	21,435	629	22,064	0.1319	2,911	--	24,975
1965	19,305	1,640	20,945	0.3058	6,405	100	27,450
1966	23,401	6,669	30,070	0.3597	10,817	500	41,387
1967	16,640	14,910	31,550	0.4347	13,717	105	45,372
1968	7,707	14,496	22,203	0.4566	10,138	14	32,355
1969	5,559	9,883	15,442	0.6451	9,963	--	25,405
1970	6,560	12,463	19,023	0.6097	11,599	50	30,672
1971	4,339	21,584	25,923	0.5586	14,482	200	40,605
1972	2,796	23,050	25,846	0.5586	14,439	468	40,753
1973	2,381	28,858	31,239	0.5586	17,452	584	49,275
1974	1,847	19,980	21,827	0.5586	12,194	890	34,911
1975	1,045	15,092	16,137	0.5586	9,015	1,827	26,979
1976	1,906	19,954	21,860	0.5586	12,212	2,462	36,534
1977	2,240	21,345	23,585	0.5586	13,176	4,610	41,371

Comments:

Column 1 - Japanese longline catch in metric tons, courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory.

Column 2 - Catch by Taiwan's high-seas longliners (>50 GT) based at foreign ports, estimated from published Taiwan catch statistics and average weights of albacore landed at Pago Pago.

Column 3 - Column 1 plus column 2

Column 4 - R is ratio of Korean catch of South Pacific albacore to total catch of this species by Japan and Taiwan, estimated from data in Skillman (1975).

Column 5 - Column 3 x column 4, except for 1958-61, which are from American Samoa cannery records.

Column 6 - Includes catch by Chile (from FAO statistics), Fiji (courtesy of Ian Brown), and New Zealand (from Habib and Cade 1978).

Table 4.--Estimated number of vessel trips, fishing days per trip, and total fishing days for longliners based at American Samoa, 1954-76.

	Japan			Taiwan			Korea		
	Days/trip	Trips	Days	Days/trip	Trips	Days	Days/trip	Trips	Days
1954	--	58	--	--	--	--	--	--	--
1955	--	142	--	--	--	--	--	--	--
1956	--	262	--	--	--	--	--	--	--
1957	17.4	263	4,576	--	--	--	--	--	--
1958	21.1	330	6,963	--	--	--	22.6	7	158
1959	24.4	287	7,003	--	--	--	26.7	14	374
1960	23.3	283	6,594	--	--	--	23.0	44	1,012
1961	21.5	260	5,590	--	--	--	25.0	8	200
1962	22.0	349	7,678	--	--	--	24.9	40	996
1963	24.6	423	10,406	--	--	--	30.9	69	2,132
1964	27.5	277	7,618	23.2	27	626	27.4	69	1,891
1965	30.7	275	8,442	27.6	97	2,677	34.2	165	5,643
1966	32.1	229	7,351	27.5	295	8,112	41.6	246	10,234
1967	35.7	202	7,211	33.0	355	11,715	44.3	241	10,676
1968	39.6	100	3,960	40.3	267	10,760	47.5	214	10,165
1969	38.7	47	1,819	38.9	213	8,286	47.3	289	13,670
1970	37.9	26	985	40.4	326	13,170	46.7	289	13,496
1971	40.2	13	523	45.3	328	14,858	54.5	282	15,369
1972	29.8	4	119	46.8	350	16,128	54.4	349	18,986
1973	--	--	--	52.2	422	22,028	56.6	479	27,111
1974	--	--	--	55.4	327	18,116	47.6	422	20,087
1975	--	--	--	62.5	134	8,375	55.8	262	14,620
1976	--	--	--	59.2	152	8,998	57.6	276	15,898

Table 5.--Mean fork length (top row, cm) and weight (bottom row, kg) of harvested South Pacific albacore by latitude, sex, and vessel nationality.

	Latitude									
	0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	40°-45°S	0°-45°S
Sex:										
Male	88.8 15.5	90.9 16.6	93.9 18.4	97.3 20.5	97.2 20.6	87.6 15.3	83.3 13.1	77.6 10.4	-- --	91.2 17.0
Female	86.8 14.4	87.6 14.8	89.8 16.0	92.4 17.5	91.7 17.2	86.6 14.5	84.1 13.3	78.8 10.9	-- --	88.0 15.1
Undeter- mined	90.6 16.5	90.6 16.6	93.3 18.1	95.4 19.4	95.3 19.4	88.7 15.8	81.9 12.6	81.0 12.1	77.9 10.6	88.2 15.6
Nation:										
Japan	88.0 15.1	90.6 16.5	93.4 18.1	96.7 20.1	95.6 19.6	87.7 15.3	83.7 13.3	75.0 9.6	-- --	-- --
Taiwan	87.9 15.0	89.6 15.9	92.6 17.7	95.1 19.2	95.4 19.4	88.6 15.7	82.3 12.7	81.7 12.5	85.6 14.8	-- --
Korea	89.2 15.7	90.0 16.1	92.5 17.6	95.3 19.3	95.1 19.3	87.3 15.1	82.7 12.9	80.7 12.0	77.9 10.6	-- --
Overall	88.8 15.5	89.9 16.1	92.7 17.7	95.5 19.4	95.3 19.4	87.8 15.3	82.8 12.9	80.8 12.1	77.9 10.6	-- --

Table 6.--Mean fork length (top row, cm) and weight (bottom row, kg)
of harvested South Pacific albacore by latitude and year.

Year	Latitude									
	0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	40°-45°S	0°-45°S
1962	--	96.0	94.4	--	--	--	--	--	--	94.4
	--	19.6	18.7	--	--	--	--	--	--	18.7
1963	--	93.5	94.4	96.2	98.5	96.3	--	--	--	94.6
	--	18.1	18.7	19.9	21.2	19.8	--	--	--	18.8
1964	--	89.5	92.8	95.6	96.0	91.2	--	--	--	91.6
	--	15.9	17.7	19.4	19.8	17.1	--	--	--	17.1
1965	91.2	89.7	92.5	96.8	93.7	88.9	--	--	--	91.5
	16.8	16.0	17.5	20.2	18.5	15.8	--	--	--	17.1
1966	91.5	90.1	93.2	96.8	97.4	90.6	85.4	--	--	91.6
	17.0	16.2	17.9	20.2	20.7	16.7	14.0	--	--	17.1
1967	88.3	89.6	92.1	96.0	97.0	84.9	86.4	--	--	89.5
	15.1	15.9	17.3	19.7	20.3	13.8	14.6	--	--	16.1
1968	88.4	89.3	91.2	94.6	96.7	87.1	79.8	--	--	88.5
	15.2	15.7	16.8	18.8	20.1	14.9	11.4	--	--	15.6
1969	88.5	89.3	92.8	95.5	92.1	87.0	83.6	--	--	89.9
	15.3	15.7	17.7	19.4	17.6	14.8	13.1	--	--	16.2
1970	86.9	88.7	91.2	94.5	88.1	84.9	82.4	78.0	--	87.9
	14.5	15.4	16.9	18.8	15.2	13.7	12.6	10.6	--	15.2
1971	90.7	90.4	92.4	95.3	95.8	89.8	81.6	80.8	--	89.5
	16.3	16.4	17.6	19.3	19.6	16.5	12.6	12.2	--	16.3
1972	91.4	90.1	92.7	94.4	94.3	88.8	86.1	80.3	--	88.6
	17.0	16.3	17.8	18.8	18.8	15.8	14.4	11.9	--	15.8
1973	91.3	90.4	91.9	94.0	94.6	87.1	82.0	82.0	--	86.3
	17.0	16.3	17.4	18.6	18.9	15.0	12.3	12.6	--	14.6
1974	89.1	90.6	92.7	96.2	95.4	91.6	79.9	79.6	77.5	84.5
	15.8	16.6	17.8	20.0	19.5	17.4	11.8	11.5	10.4	13.9
1975	91.6	91.9	95.4	95.0	97.4	93.1	91.0	91.5	80.4	93.0
	17.1	17.2	19.3	19.0	20.6	18.1	17.0	17.1	11.8	18.0
1976	87.4	91.1	95.3	96.7	95.9	89.0	89.1	88.9	--	92.2
	15.0	16.9	19.3	20.3	19.8	16.0	16.0	15.9	--	17.7
All years	88.8	89.9	92.7	95.5	95.3	87.8	82.8	80.8	77.9	--
	15.5	16.1	17.7	19.4	19.4	15.3	12.9	12.1	10.6	--

Table 7.--Mean fork length (top row, cm) and weight (bottom row, kg) of harvested South Pacific albacore by year and vessel nationality.

Year	Japan	Taiwan	Korea	All nations
1962	94.4	--	--	94.4
	18.7	--	--	18.7
1963	94.8	--	93.7	94.6
	18.9	--	18.2	18.8
1964	91.7	93.1	90.4	91.6
	17.2	17.9	16.4	17.1
1965	91.9	90.5	91.3	91.5
	17.3	16.4	16.9	17.1
1966	91.4	91.6	91.7	91.6
	17.1	17.1	17.2	17.1
1967	87.5	89.9	90.7	89.5
	15.2	16.2	16.7	16.1
1968	84.5	89.4	89.3	88.5
	13.7	15.9	16.0	15.6
1969	86.6	90.3	90.2	89.9
	14.7	16.3	16.4	16.2
1970	84.8	89.7	86.6	87.9
	13.8	16.0	14.7	15.2
1971	79.2	89.4	89.8	89.5
	12.1	16.2	16.5	16.3
1972	99.9	91.6	86.6	88.6
	22.3	17.2	14.9	15.8
1973	--	88.9	84.9	86.3
	--	15.8	14.0	14.6
1974	--	86.6	83.1	84.5
	--	15.0	13.2	13.9
1975	--	93.3	92.6	93.0
	--	18.1	17.8	18.0
1976	--	92.6	92.0	92.2
	--	17.9	17.6	17.7

Table 8.--Estimated percentage of total nominal effort (10^3 hooks) by latitude for longliners of Taiwan and Korea based at American Samoa, 1964-77.

Year	Nation	Latitude								Effort (10 ³ hooks)
		0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	
1964	Taiwan	0	16.9	76.1	5.1	1.3	0.6	0	0	611
	Korea	0	45.9	53.9	0.2	0	0	0	0	1,280
1965	Taiwan	2.7	62.8	21.7	8.7	0.3	3.8	0	0	1,881
	Korea	0.2	54.4	34.5	6.3	1.5	3.1	0	0	4,708
1966	Taiwan	0.4	36.7	36.8	9.5	4.4	12.2	0	0	7,405
	Korea	0.4	44.2	28.4	13.3	0.5	10.1	3.1	0	10,061
1967	Taiwan	1.0	33.2	27.4	14.0	3.1	17.2	4.0	0.1	13,373
	Korea	2.2	31.8	27.5	19.5	2.1	7.1	9.5	0.3	15,378
1968	Taiwan	2.8	52.3	20.3	9.9	3.6	8.7	2.4	0	12,219
	Korea	10.3	41.8	15.6	15.3	1.3	10.0	5.7	0	14,276
1969	Taiwan	4.8	53.1	29.8	6.6	1.4	3.1	1.2	0	9,554
	Korea	12.7	40.5	19.0	10.7	1.5	13.8	1.8	0	20,681
1970	Taiwan	3.6	45.0	29.5	11.0	2.4	6.3	2.2	0	13,746
	Korea	9.5	27.1	16.9	15.6	1.6	16.6	10.8	1.9	20,405
1971	Taiwan	7.4	31.5	21.9	16.0	4.8	10.2	7.5	0.7	12,891
	Korea	6.3	17.4	16.8	21.8	6.3	14.5	13.0	3.9	21,994
1972	Taiwan	5.8	37.7	25.7	12.0	4.9	10.9	2.6	0.5	12,885
	Korea	10.2	21.8	19.2	14.4	2.9	13.7	5.4	12.4	21,603
1973	Taiwan	1.2	32.2	20.9	12.0	4.4	19.5	6.9	2.9	15,541
	Korea	5.6	19.9	13.6	6.8	6.5	19.3	14.4	13.9	32,682
1974	Taiwan	2.3	18.5	20.6	18.0	4.3	10.8	9.0	16.5	14,088
	Korea	16.9	14.2	11.7	12.0	9.7	7.5	9.8	18.2	27,872
1975	Taiwan	3.5	33.0	33.0	8.9	3.4	11.6	2.0	4.6	7,933
	Korea	13.1	44.5	24.1	8.3	4.2	2.8	1.2	1.8	19,876
1976	Taiwan	1.0	17.0	43.0	12.2	2.9	15.7	3.8	4.4	6,267
	Korea	5.4	25.4	18.0	22.8	7.3	17.0	1.9	2.2	22,514
1977	Taiwan	0.8	32.6	24.1	15.2	4.2	13.6	5.9	3.6	9,980
	Korea	7.1	28.8	20.9	11.0	7.8	14.5	6.3	3.6	25,041

Table 9.--Estimated relative fishing power, by nationality of vessel, with respect to the harvest of South Pacific albacore.

Nation	Data sets	Relative fishing power
Japan*	American Samoa	1.00
Taiwan	American Samoa	1.85
Korea	American Samoa	1.25
Japan	Far Seas Fisheries Research Laboratory	0.82

*Standard

Table 10.--Total catch of South Pacific albacore (MT), index of abundance (kg/100 hooks), and estimated total effective effort (10^6 hooks).

Year	Total catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)
1962	39,479	146.00	27
1963	35,475	85.76	41
1964	24,975	75.39	33
1965	27,450	72.02	38
1966	41,387	63.66	65
1967	45,372	42.56	107
1968	32,355	33.76	96
1969	25,405	41.03	62
1970	30,672	35.42	87
1971	40,605	29.90	136
1972	40,753	21.45	190
1973	49,275	20.19	244
1974	34,911	13.86	252
1975	26,979	13.64	198
1976	36,534	18.00	203
1977	41,371	21.71	191

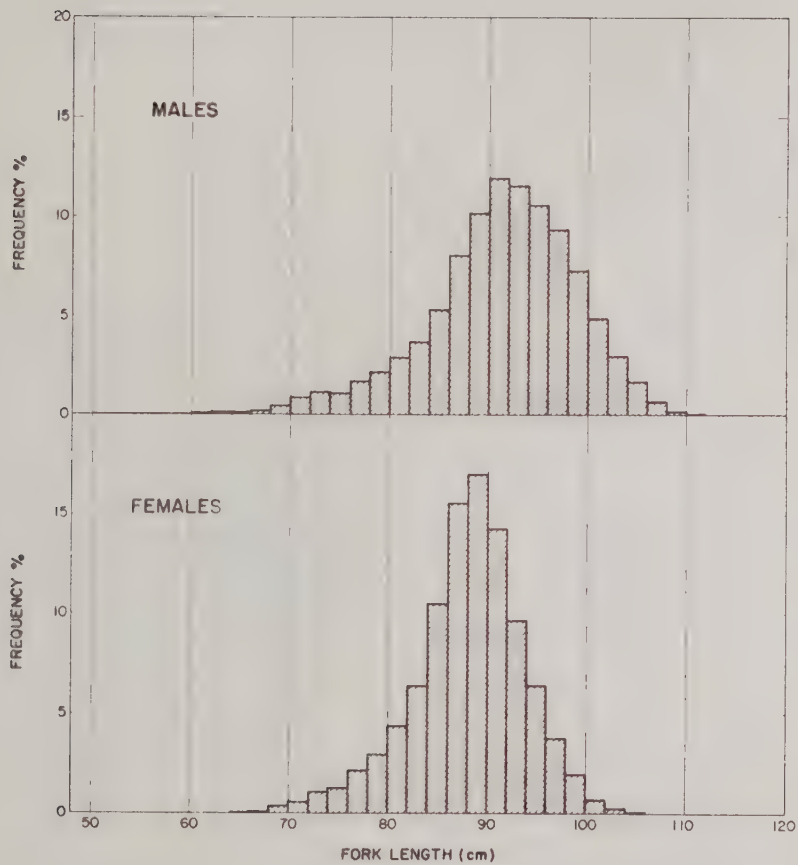


Figure 2.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by sex, 1962-70.

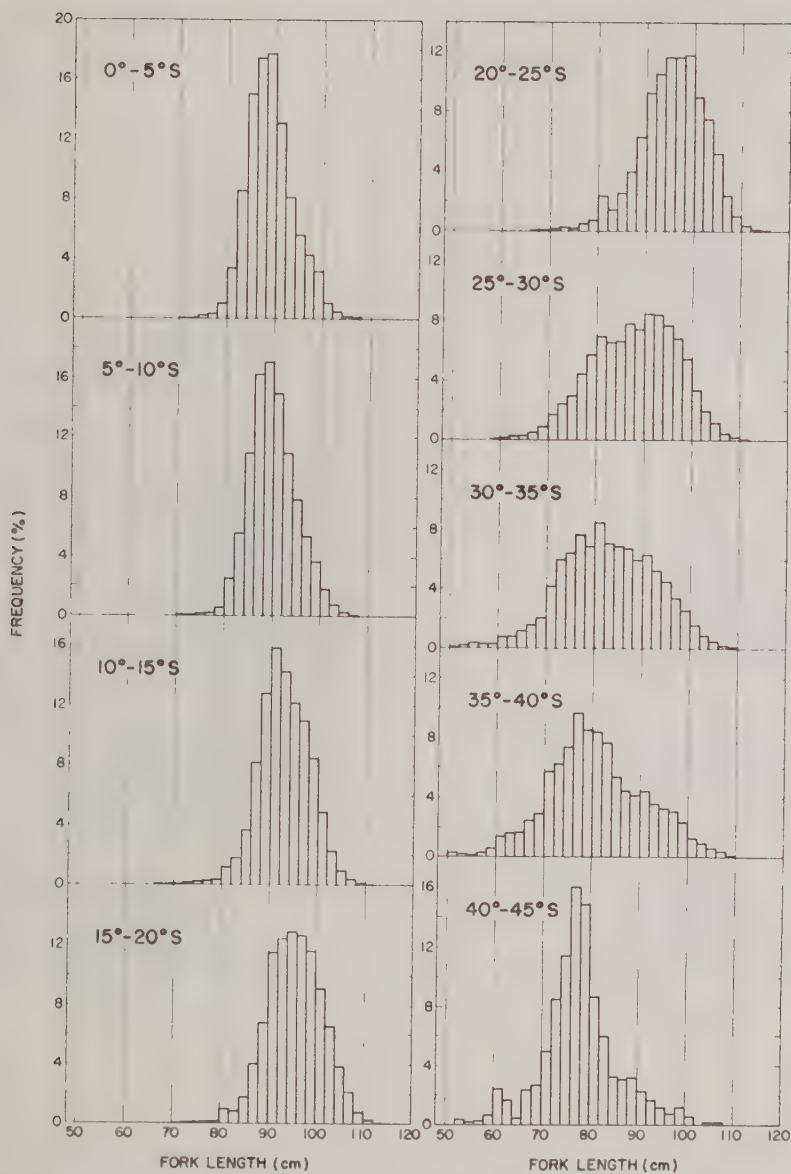


Figure 3.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by latitude, 1962-76.

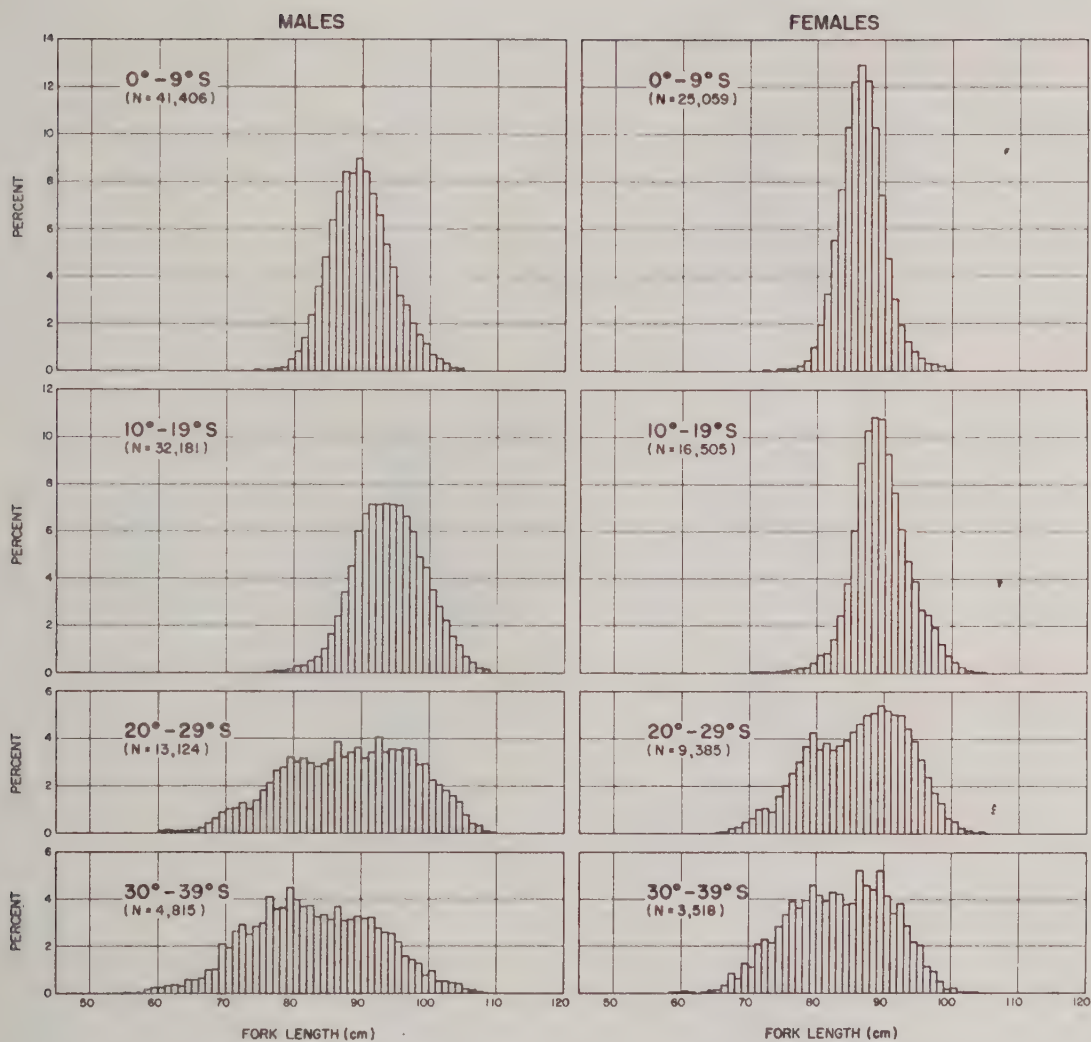


Figure 4.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by latitude and sex, 1962-70 (from Yoshida 1975).

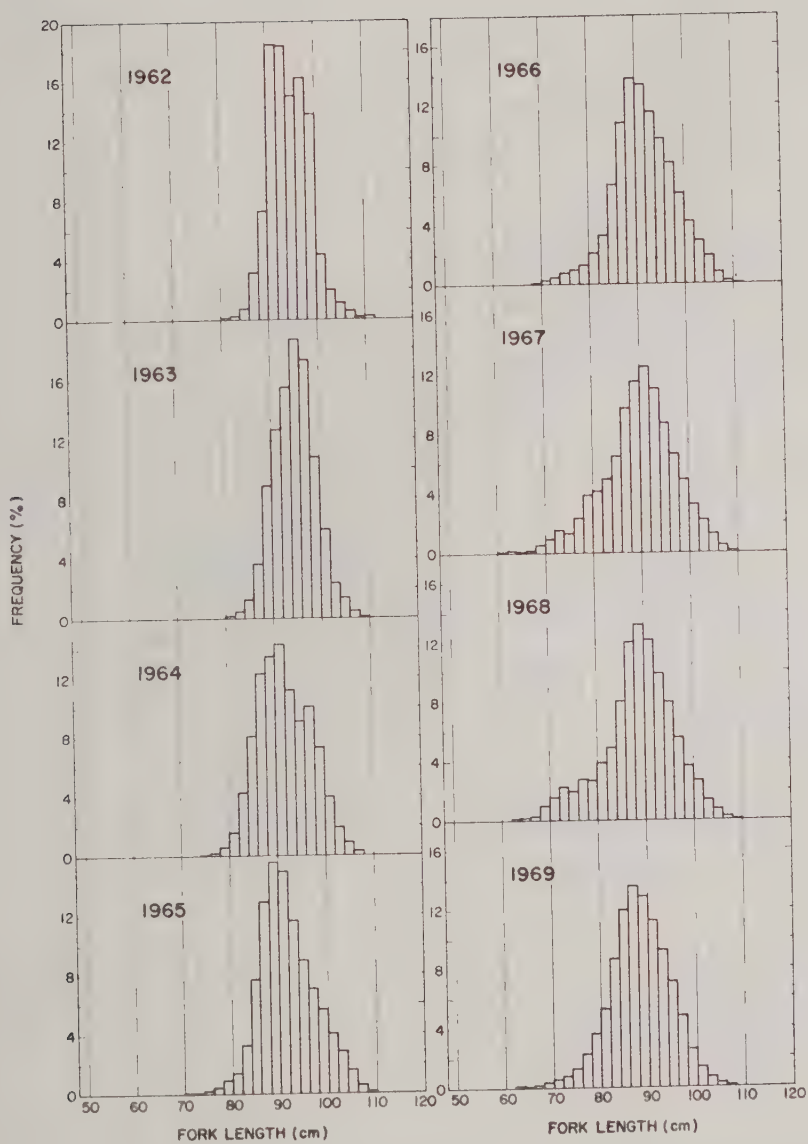


Figure 5.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by year, 1962-76.

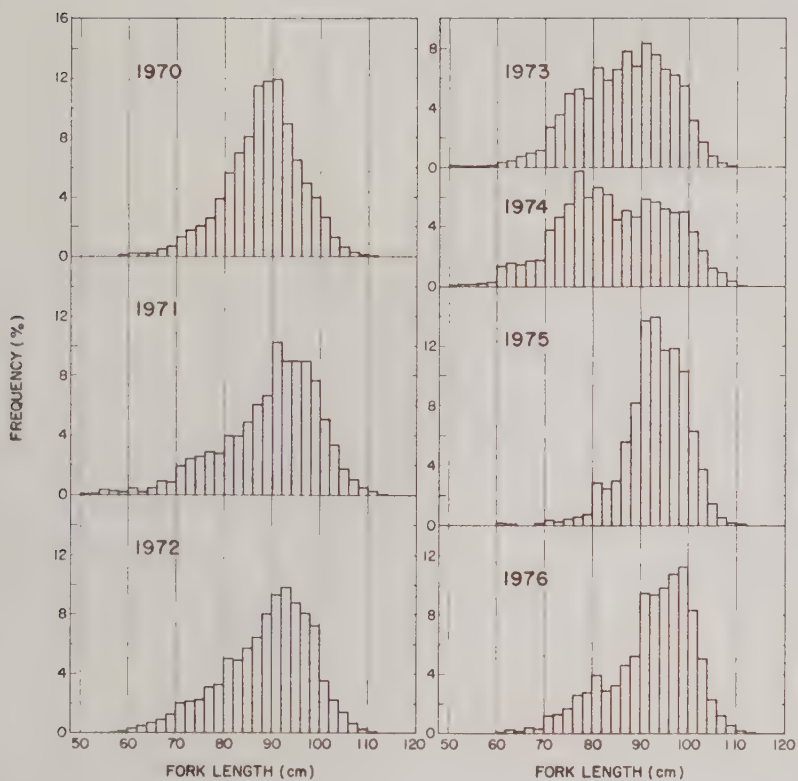


Figure 5.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by year, 1962-76.--Continued.

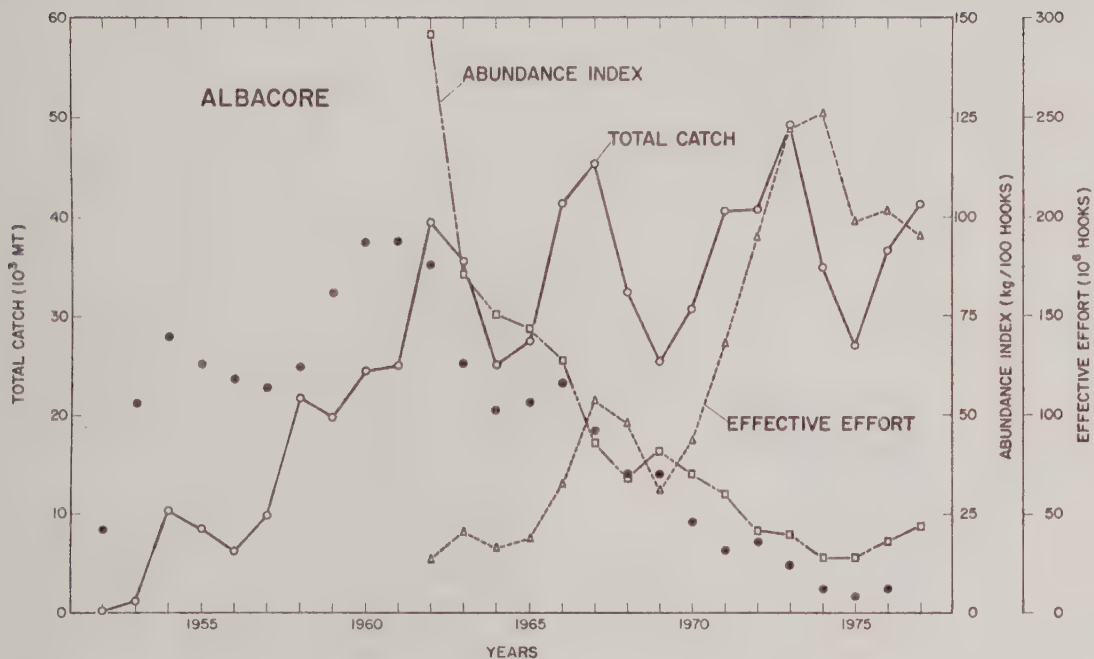


Figure 6.--Estimated total catch (10^3 MT), abundance index (kg/100 hooks), and effective effort (10^6 hooks) for South Pacific albacore. Solid circles denote a second abundance index based on historical Japanese longline statistics.

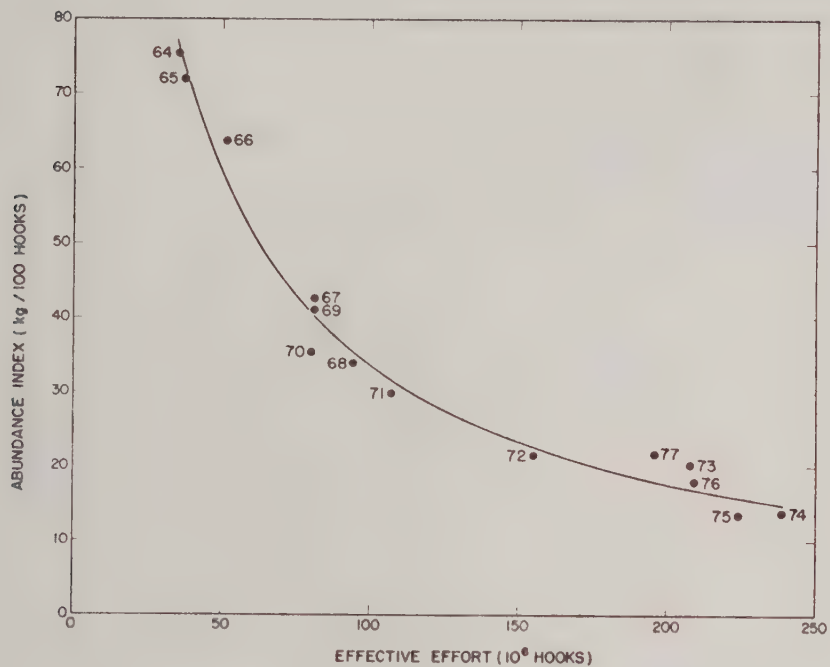


Figure 7.--Fitted production model for South Pacific albacore,
based on 3-year effort averaging.

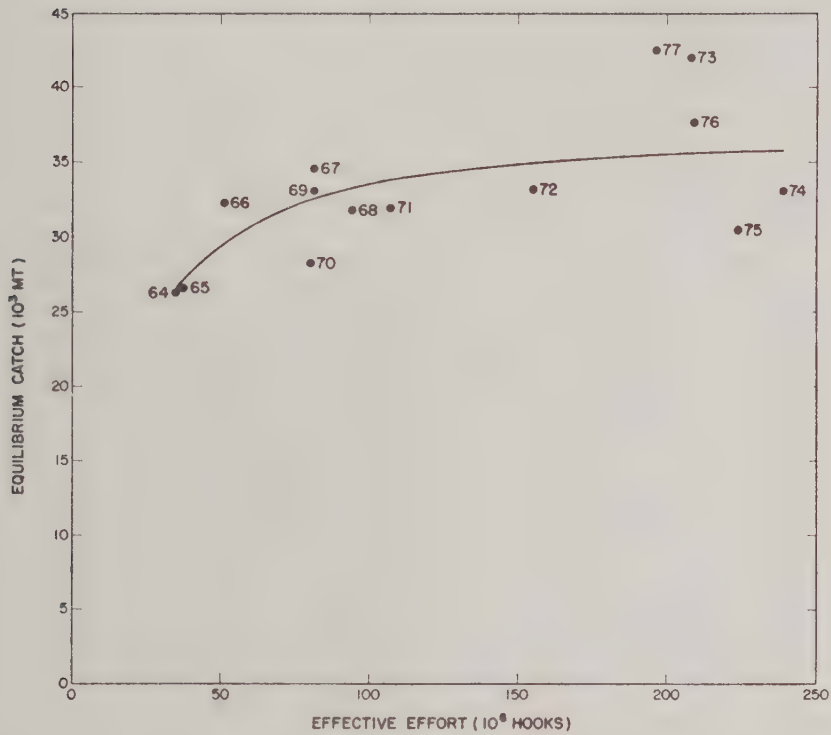


Figure 8.--Projected relationship between equilibrium yield and effective effort for South Pacific albacore, based on production model with 3-year effort averaging.

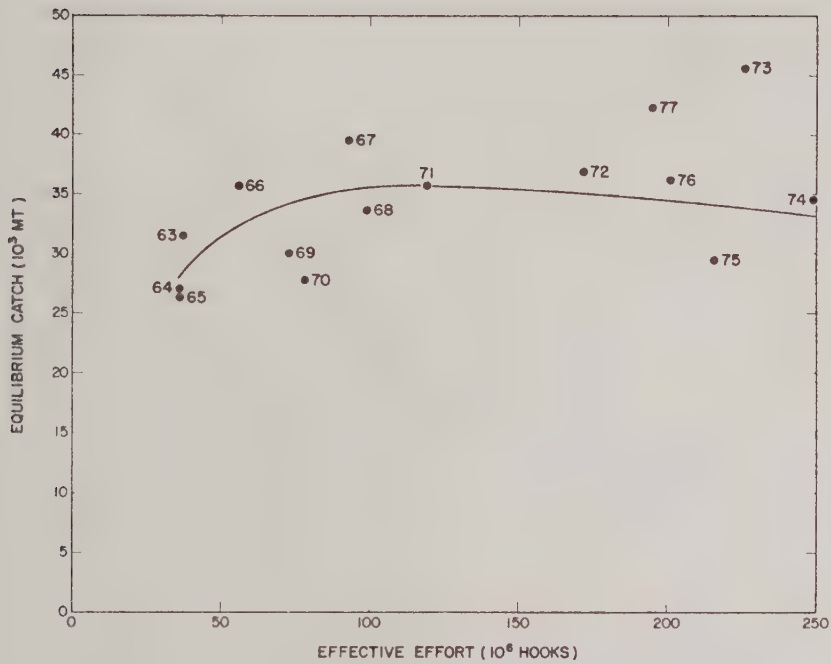


Figure 9.--Projected relationship between equilibrium yield and effective effort for South Pacific albacore, based on production model with 2-year effort averaging.

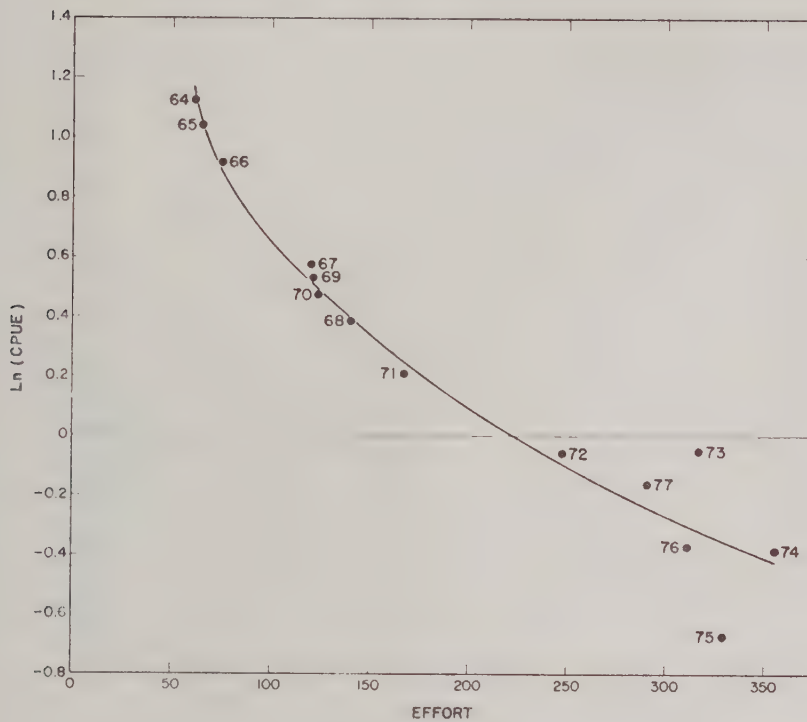


Figure 10.--Relationship between natural logarithm of abundance and effective effort for South Pacific albacore.

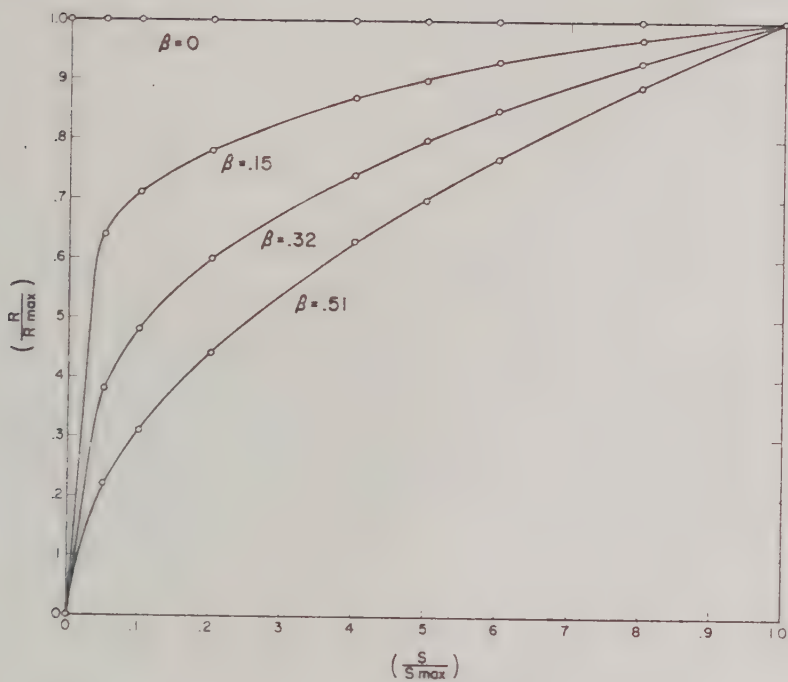


Figure 11.--Hypothetical relationships between recruitment of 2-year olds (R) and the spawning biomass (S) used in the South Pacific albacore simulation model.

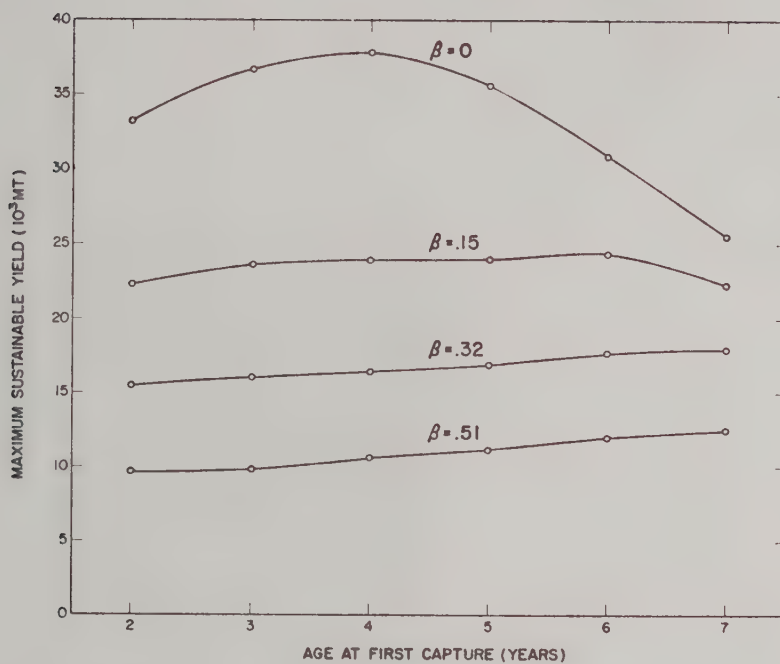


Figure 12.--Predicted relationships between maximum sustainable yield and age at first capture under different assumed stock-recruit relationships for South Pacific albacore.

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2

SOME PRODUCTION MODEL ANALYSES OF TUNA AND BILLFISH STOCKS
IN THE INDIAN OCEAN

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PURPOSE AND SCOPE

This report summarizes some production model analyses of tuna and billfish stocks in the Indian Ocean, using historical total catch statistics and abundance indices computed from longline catch per unit effort data. The purpose is to get a rough idea of the status of the stocks; time and resources did not permit a thorough analysis. Size-composition data were not evaluated, and the completeness and reliability of total catch statistics is open to question. In the case of albacore, yellowfin, and bigeye tuna stocks, the production model results will be compared to earlier assessments by Suda (1973, 1974).

DATA SOURCES

Annual total catch statistics in metric tons (MT) were provided for Japan (1952-77) and Taiwan (1962-77) by S. Ueyanagi of the Far Seas Fisheries Research Laboratory, Shimizu, Japan, and R. T. Yang of National Taiwan University (Tables 1-8). Billfish catches for Taiwan were provided with species combined for 1963-66, so the breakdown by species in these years was estimated by applying the average species composition for 1967 and 1968. No data were available for the catch by longliners from the Republic of Korea except for FAO statistics on tuna catches (1965-76) and the catches of blue marlin, swordfish, and sailfish (1975-76). To estimate the Korean catches of blue marlin for 1965-74 we computed the ratio of blue marlin catch to yellowfin catch during 1975 and 1976 and assumed this ratio prevailed in the earlier years also. To estimate the missing Korean catch figures for other billfish species we computed

the ratio of estimated Korean blue marlin catch to the blue marlin catch by Taiwan in each year and multiplied this times the catch of the given species by Taiwan. These procedures clearly give only a very rough estimation of the Korean catches.

Concerning the catches by countries other than Japan, Taiwan, and Korea, we used statistics from various FAO compilations (FAO 1974, 1975, 1977). These included estimates of longline catches by the U.S.S.R. and Sri Lanka, and surface yellowfin catches by Australia, India, Madagascar, Maldives, Pakistan, Sri Lanka, Democratic Republic of Yemen, Seychelles, and Oman.

Statistics on nominal effort in hooks and associated catch in number of fish by month and 5° square were available for Taiwan (1967-77) and Japan (1952-76).

INDICES OF ABUNDANCE AND EFFECTIVE EFFORT

Annual abundance indices for each species were constructed in the manner described by Wetherall et al. (1979), using the detailed Japanese catch and nominal effort statistics and average weight estimates computed over the entire ocean (Table 9). Index areas were selected after consideration of stock structure information in Suda (1974) and examination of plots of spatial variation in average catch rates (Figures 1 through 8). Boundaries of the selected index areas are as follows:

<u>Species</u>	<u>Latitude</u>	<u>Longitude</u>
Albacore	0°-45°S	20°-120°E
Yellowfin tuna	15°N-15°S	40°-100°E
Bigeye tuna	15°N-35°S	40°-110°E
Blue marlin	10°N-25°S	40°-100°E
Striped marlin	20°N-30°S	20°-125°E
Black marlin	20°N-25°S	90°-125°E
Swordfish (1)	20°N-15°S	45°-100°E
(2)	20°S-45°S	20°-55°E
Sailfish (1)	20°N-5°S	45°-100°E
(2)	0°-30°S	35°-50°E

Effective effort was computed by dividing the abundance indices into appropriate annual total catch statistics (Tables 10 and 11; Figures 9 through 14). Abundance indices and effective effort were standardized to Japanese data in the first year of each time series.

PRODUCTION MODELS

The PRODFIT program by Fox (1975) was used to fit production models to abundance indices and the associated measures of effective effort. Effort was averaged over 1-, 2-, 3-, and 4-year periods to approximate equilibrium conditions.

Results are summarized in Tables 12 and 13, and Figures 17 through 22, and are evaluated here species by species:

Albacore

The total albacore catch rose steadily in the first decade of the fishery to about 17,700 MT and then fluctuated rather markedly after 1962 (Table 10). The highest catch of 28,250 MT was taken in 1974. The abundance index tripled in the first few years of the fishery, but has since declined steadily to less than one-tenth its peak value (Figure 9).

The production model analysis (Table 12) gives a best estimate of maximum sustainable yield (MSY) equal to about 17,800 MT at an infinitely high effective effort. However, the yield curve is very flat over a wide range of effort, and an average catch nearly equal to the MSY could apparently be achieved at an effort significantly less than the 1976 level (Figure 17).

Suda (1973) estimated the MSY for Indian Ocean albacore to be in the range of 20,000-25,000 MT. We believe much of the discrepancy between our estimate and his can be accounted for by the tendency of his total catch estimates to be greater than ours. At any rate, the conclusion of both analyses is that the stock is fully harvested. The failure of the total catch to increase significantly in spite of the expansion of fishing effort south of lat. 30°S during the 1960's and 1970's (Table 14) is consistent with Suda's yield per recruit assessments (and similar analyses on other albacore stocks) which suggest no gain in yield per recruit from harvesting the younger fish found in the more southerly waters.

Bigeye tuna

Total catch of bigeye tuna in the Indian Ocean increased fairly steadily until 1968, when almost 39,000 MT were taken, and then fell in the next 5 years to only about 15,000 MT in 1973. It then roughly doubled, ranging between 26,448 to 38,359 MT during the next 3 years. The decline in total catch between 1968 and 1973 was experienced by all three longline fleets, whereas the increase in total catch estimates during 1974-76 was due mostly to a reported rise in the Korean catch (Table 2). The abundance index for bigeye has fluctuated moderately but has shown a definite downward trend since the inception of longlining. However, the apparent abundance is still about 50% of its initial level (Figure 10).

The production model analysis (Table 12) gives two different results, depending on the number of years over which effective effort is averaged. With 1- or 2-year averaging, the estimated MSY is 59,000-60,000 MT at infinitely high effort. On the other hand, smoothing by 3 or 4 years gives an MSY of about 30,600 to 32,500 MT at effort levels only slightly greater than recent ones (Figure 18). The analysis is quite sensitive to the choice of smoothing period because there are no observations to clearly define either the right hand side of a dome-shaped production curve or the flat top of an asymptotic one. Suda had similar difficulties in establishing the behavior of the yield curve and high efforts. He concluded that MSY was about 30,000 MT for the whole Indian Ocean, and could be realized by roughly doubling effective effort over the 1970-71 level. This is consistent with our findings when the 3- or 4-year effort averaging is chosen.

Yellowfin tuna

During the early years of Japanese longlining in the Indian Ocean, yellowfin tuna were a primary target and the total catch of yellowfin tuna rose quickly as effort was concentrated in good yellowfin tuna grounds. The peak Japanese yellowfin tuna catch of about 52,000 MT was in 1962, and annual Japanese harvests varied widely from 25,000-50,000 MT throughout the 1960's. During the 1970's the Japanese catch has been much lower, well under 10,000 MT in most years (Table 3) as effort has shifted away from the equatorial yellowfin tuna grounds. The catch by Taiwan reached high levels in 1968-71, but has been less than 5,000 MT in most other years. According to FAO statistics, the longline catch of Indian Ocean yellowfin tuna since 1972 has been dominated by Korea.

Besides the longline fishery for yellowfin tuna there is a substantial surface fishery. While the surface catch is very poorly documented, various FAO records show that it has increased dramatically during the 1970's, with catches in 1975 and 1976 exceeding 20,000 MT (not including the harvest by Sri Lanka which was probably about 5,000 MT each year). The surface fishery takes yellowfin tuna mostly 2 years old or younger (FAO 1974) whereas the longliners harvest predominantly 2- and 3-year olds (Suda 1974). In recent years the decline in total longline harvest has been balanced by the increase in surface catch (Table 3).

While it has been hypothesized that at least two stocks of Indian Ocean yellowfin tuna exist, east and west of approximately long. 90°E, we were unable to break our total catch statistics down into the two hypothesized regions. Therefore we fit a production model to the aggregated statistics for the whole ocean. The abundance index for the

region has shown a steady decline since 1954 to levels perhaps only one-fifth or one-sixth as high as at the inception of fishing (Figure 11). With smoothing periods of 2 or 3 years, the MSY is estimated to be about 43,000-45,400 MT. This can be compared to Suda's estimate of about 35,000 MT. Under all averaging periods considered the equilibrium yield curve (Figure 19) is essentially asymptotic to MSY, and the analysis suggests that no substantial increase in average annual yield can be achieved. From 1970 to 1976 the effective effort by longliners has been relatively steady while effective effort by surface fleets has quadrupled. Although the stock size has declined during this period, the total catch has been relatively constant. The fraction taken by surface fisheries has grown while the longline catch has diminished.

Blue Marlin

Information on the population biology of blue marlin in the Indian Ocean is virtually non-existent. Assuming a single stock, our abundance index for blue marlin suggests a fairly steady decline since the beginning of Japanese longlining in 1952, except for a momentary increase during 1972-74 (Figure 12). Total catch apparently peaked in 1956 at about 5,000 MT, fluctuated between 2,600 and 4,300 MT thereafter through 1970, and has usually been less than 2,500 MT in more recent years. Note that the Korean catch totals were roughly estimated in all years except 1975 and 1976 (Table 4).

The production models for blue marlin (Table 13) suggest an MSY of 3,400-3,600 MT achievable at an effort substantially less than any recent level (Figure 20), but the curves fit poorly. There may be significant errors in our total catch estimates.

Striped Marlin

As with blue marlin, no assessment work has yet been done with Indian Ocean striped marlin. However, the distribution and biology of striped marlin taken by the Japanese tuna longline fishery in the Indian Ocean has been studied, most recently by Pillai and Ueyanagi (1978).

Our statistics (Table 5) show that the total catch fluctuated between 800 and 2,400 MT annually from 1954 through 1964. Relatively high catches were taken in the following 6 years. During the 1970's the estimated catch dropped off considerably until 1976. The decline of Japanese longline catches during the 1970's is due in part to a shift of effort to more southerly waters where striped marlin are much less abundant. The Korean catches are estimated very roughly, as mentioned earlier.

The abundance index for striped marlin, assuming a single stock, shows a fair degree of annual variation, but the overall trend in stock size since the beginning of longlining is downward to a level perhaps one-fourth of the original abundance. The index has increased steadily over 1972-76 (Figure 13). The production model analysis for striped marlin gives an MSY of about 3,500 MT at an effort level above any yet experienced. The yield curve is very flat over a broad range of efforts (Figure 21).

Black Marlin

The total Indian Ocean catch of black marlin ranged from 1,100 to 1,600 MT during 1954-67, then reached the highest levels on record during 1968-69. The average catch during the 1970's has been substantially

lower (Table 5, Figure 14). As in the Pacific Ocean, black marlin abundance is apparently greatest in coastal regions. The highest catch rates are seen in the eastern Indian Ocean. On the basis of catch rates, other concentrations also exist off southern Africa and Saudi Arabia.

The stock structure of black marlin is unknown. There may be more than one stock in the Indian Ocean, and interactions between the species in the eastern Indian Ocean and western Pacific (Shomura 1978). For the purposes of our analysis we considered the aggregate catch of black marlin in the Indian Ocean and assumed trends in the index for the eastern area were representative of trends in average abundance throughout the ocean. The index (Figure 14) shows a definite declining trend from the early 1950's until the present. The estimated MSY (Table 13) is 1,400-1,500 MT. Optimum effort is less than recent levels, but the yield-effort curve is quite flat (Figure 22). The equilibrium data points for 1972-76 are clustered below the expected yield curve, whereas the points for 1968-71 are above it, suggesting the possibility of some systematic bias in the above estimates.

Swordfish

While the distribution of catch rates in Figure 7 does not show it clearly, due to the scaling chosen for the plot, there seem to be two areas where densities of swordfish are relatively high. We constructed abundance indices in both areas (Table 11, Figure 15). Total catch of swordfish increased steadily from the early 1950's up through the 1960's, but has decreased during the 1970's. Both indices suggest rather marked variations in abundance, although an early decline in stock size through

the mid-1960's is apparent. Since then the indices have been erratic with no evidence of sustained stock decrease in spite of a relatively large increase in average annual catch. The data suggest that longlining has had no significant impact on the swordfish population, (for example, stock size has not been reduced below about 65% of its original level), so no production model analysis was attempted.

Sailfish

The "sailfish" catch contains an unknown percentage of shortbill spearfish, the proportion of spearfish being higher in offshore areas. However, the population dynamics of these species may be rather similar, so we may assume similar responses to exploitation. Two index areas were selected, based on average catch rates. As shown in Table 11 and Figure 16, total catch in the Indian Ocean climbed from about 200 MT in 1954 to nearly 2,000 MT in 1968. Since then it has declined, and the reported longline catch was less than 1,000 MT per year during 1974-76.

The stock abundance indices show considerable variability, with much higher variation in the more northerly index area. In general a long-term increase in apparent abundance of sailfish is evident, particularly in the southern index region. In neither case is there any indication that the stock has been affected by fishing, and we conclude that the potential yield for sailfish is much higher than the maximum annual catch taken thus far.

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Table 1.--Estimated annual catches (metric tons) of Indian Ocean albacore, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	U.S.S.R. ⁴	Total
1952	67				67
1953	1,099				1,099
1954	2,759				2,759
1955	3,302				3,302
1956	4,821				4,821
1957	4,664				4,664
1958	6,285				6,285
1959	10,412				10,412
1960	11,066				11,066
1961	15,438				15,438
1962	17,668				17,668
1963	12,546	74			12,620
1964	17,874	210	--		18,084
1965	11,375	22	500	500	12,397
1966	13,130	2,646	500	1,000	17,276
1967	14,098	5,205	2,900	1,500	23,703
1968	10,034	6,135	600	600	17,369
1969	8,546	9,427	3,000	900	21,873
1970	4,684	6,436	3,000	1,100	15,220
1971	3,140	4,346	2,100	600	10,186
1972	1,257	6,278	3,600	600	11,735
1973	1,835	10,570	9,000	900	22,305
1974	2,606	15,438	9,206	⁵ 1,000	28,250
1975	1,168	5,794	3,243	⁵ 1,000	11,205
1976	1,166	8,924	3,847	⁵ 1,000	14,937
1977	404	9,502	--	--	--
1978	--	7,824	--	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan

³FAO (1977).

⁴FAO (1974, 1975)

⁵Guessed value.

Table 2.--Estimated annual catches (metric tons) of Indian Ocean
bigeye tuna, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Sri Lanka ⁴	U.S.S.R. ⁴	Yemen ³	Total
1952	1,500						1,500
1953	3,600						3,600
1954	7,900						7,900
1955	6,060						6,060
1956	8,040						8,040
1957	12,400						12,400
1958	11,300						11,300
1959	8,900						8,900
1960	15,700						15,700
1961	13,500						13,500
1962	18,700	1,226					19,926
1963	12,400	1,653			100		14,153
1964	16,700	1,771	--		400		18,871
1965	18,200	1,362	100		500		20,162
1966	22,600	2,175	100	100	1,400		26,375
1967	22,400	2,324	200	100	2,000		27,024
1968	24,600	7,209	5,400	200	1,300		38,709
1969	15,000	7,980	10,000	200	1,100		34,280
1970	13,600	7,604	11,000	100	1,800		34,104
1971	11,700	5,701	4,100	100	1,100		22,701
1972	8,800	4,143	4,300	100	800		18,143
1973	5,700	2,955	5,600	100	600		14,955
1974	7,700	4,448	13,300	--	⁵ 1,000		26,448
1975	8,500	4,005	24,691	--	⁵ 1,000	163	38,359
1976	2,900	3,165	21,018	--	⁵ 1,000	163	28,246
1977	5,200	5,170	--	--	--	--	--
1978	--	1,601	--	--	--	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan.

³FAO (1977).

⁴FAO (1974, 1975).

⁵Guessed value.

Table 3.--Estimated annual catches (metric tons) of Indian Ocean yellowfin tuna, by nation and year.

Year	Longline catch				Sri Lanka ³	Total longline	Surface catch								Total surface	Grand total	
	Japan ¹	Taiwan ²	Korea ³	U.S.S.R. ³			Australia ⁴	Bangladesh ⁴	India ⁴	Madagascar ⁴	Maldives ⁴	Pakistan ⁴	Sri Lanka ⁴	Seychelles ⁴			Yemen ⁴
1952	8,858					8,858											8,858
1953	13,258					13,258											13,258
1954	24,883					24,883											24,883
1955	27,875					27,875											27,875
1956	38,641					38,641											38,641
1957	36,036					36,036											36,036
1958	25,727					25,727											25,727
1959	24,428					24,428											24,428
1960	40,292					40,292											40,292
1961	34,551					34,551											34,551
1962	51,665	3,468				55,133											55,133
1963	25,888	3,402		100		29,390											29,390
1964	24,752	2,859		300	200	28,111							2,000				30,111
1965	27,579	2,180	0	900	200	30,859		100	800		500		1,700				3,600
1966	44,106	4,368	100	2,600	200	51,374		200	1,000		1,500		2,000				5,400
1967	31,597	3,380	200	3,100	300	38,577		100	1,000		1,700		2,600				6,200
1968	50,475	22,646	4,000	2,700	400	80,221		100	1,300		1,700		4,100				7,900
1969	25,228	21,089	7,000	1,600	400	55,317			1,100		1,800		3,800				7,400
1970	14,459	11,865	8,000	2,000	300	36,624			500		1,200		4,000				6,000
1971	13,471	16,536	6,500	1,500	200	38,207	100		200		1,300		3,800				5,600
1972	8,880	8,833	9,600	1,600	100	29,013	100		200	200	5,000		5,100				10,900
1973	7,470	4,216	9,200	900	100	21,886			200	500	5,200		5,000	100	7,400		18,600
1974	7,935	3,147	11,563	--	--	22,645			200	1,700	4,500	--	--	150	7,391		13,941
1975	8,577	3,371	11,694	--	--	23,642			--	--	4,200	--	--	100	7,391	8,500	20,191
1976	3,507	2,545	12,848	--	--	18,900			--	--	4,800	--	--	50	7,391	8,280	20,521
1977	3,521	6,690	--	--	--	--			--	--	--	--	--	--	--	--	--
1978	--	2,114	--	--	--	--			--	--	--	--	--	--	--	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan.

³FAO (1977).

⁴FAO (1974, 1975).

⁵Incomplete.

Table 4.--Estimated annual catches (metric tons) of Indian Ocean
blue marlin, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Total
1952	800			800
1953	2,000			2,000
1954	3,300			3,300
1955	3,600			3,600
1956	4,980			4,980
1957	3,800			3,800
1958	4,100			4,100
1959	4,300			4,300
1960	3,700			3,700
1961	3,200			3,200
1962	3,100			3,100
1963	1,800	834		2,634
1964	2,900	840		3,740
1965	3,300	578	0	3,878
1966	3,300	446	8	3,754
1967	3,400	658	16	4,074
1968	2,300	1,410	326	4,036
1969	1,800	1,504	571	3,875
1970	1,200	1,185	653	3,038
1971	1,000	1,002	530	2,532
1972	900	826	783	2,509
1973	600	540	751	1,891
1974	900	526	944	2,370
1975	700	447	1,130	2,277
1976	300	343	872	1,515
1977	300	452	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

³1965-74 estimated; see text. 1975-76 from FAO (1977).

Table 5.--Estimated annual catches (metric tons) of Indian Ocean striped marlin, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Total
1952	100			100
1953	300			300
1954	800			800
1955	780			780
1956	1,740			1,740
1957	1,800			1,800
1958	1,700			1,700
1959	2,100			2,100
1960	2,000			2,000
1961	2,400			2,400
1962	1,800			1,800
1963	1,300	483		1,783
1964	1,400	486		1,886
1965	3,000	335	0	3,335
1966	3,900	258	5	4,163
1967	4,200	257	6	4,463
1968	2,300	923	213	3,436
1969	2,200	1,833	696	4,729
1970	1,700	909	501	3,110
1971	1,000	714	378	2,092
1972	800	365	346	1,511
1973	500	258	359	1,117
1974	1,400	501	899	2,800
1975	900	344	870	2,114
1976	500	819	2,082	3,401
1977	500	1,401	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University; 1963-66 estimated.

³Estimated, see text.

Table 6.--Estimated annual catches (metric tons) of Indian Ocean black marlin, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Total
1952	300			300
1953	800			800
1954	1,100			1,100
1955	1,080			1,080
1956	1,500			1,500
1957	1,400			1,400
1958	1,200			1,200
1959	1,200			1,200
1960	1,700			1,700
1961	1,400			1,400
1962	1,800			1,800
1963	1,100	351		1,451
1964	1,300	354		1,654
1965	1,100	244	0	1,344
1966	1,200	188	3	1,391
1967	1,300	242	6	1,548
1968	1,700	617	143	2,460
1969	1,300	753	286	2,339
1970	900	609	336	1,845
1971	700	481	254	1,435
1972	200	356	337	893
1973	200	213	296	709
1974	400	337	605	1,342
1975	500	192	495	1,187
1976	200	78	198	476
1977	100	120	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

³Estimated, see text.

Table 7.--Estimated annual catches (metric tons) of Indian Ocean swordfish, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Total
1952	<100			<100
1953	100			100
1954	200			200
1955	240			240
1956	480			480
1957	300			300
1958	500			500
1959	500			500
1960	600			600
1961	700			700
1962	900			900
1963	700	351		1,051
1964	900	354		1,254
1965	1,100	244	0	1,344
1966	1,200	188	3	1,391
1967	1,600	226	5	1,831
1968	1,200	626	145	1,971
1969	1,200	786	298	2,284
1970	1,000	809	446	2,255
1971	800	512	271	1,583
1972	800	387	367	1,554
1973	500	271	377	1,148
1974	600	419	752	1,771
1975	700	291	244	1,235
1976	300	371	398	1,069
1977	300	400	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University; 1963-66 estimated.

³1965-74 estimated; see text. 1975-76 from FAO (1977).

Table 8.--Estimated annual catches (metric tons) of Indian Ocean sailfish, by nation and year.

Year	Japan ¹	Taiwan ²	Korea ³	Total
1952	<100			<100
1953	100			100
1954	200			200
1955	180			180
1956	300			300
1957	300			300
1958	400			400
1959	500			500
1960	500			500
1961	500			500
1962	800			800
1963	500	175		675
1964	600	177		777
1965	1,100	122	0	1,222
1966	1,200	94	2	1,296
1967	1,900	70	2	1,972
1968	1,200	349	81	1,630
1969	700	353	134	1,187
1970	600	268	148	1,016
1971	800	359	190	1,349
1972	600	280	265	1,145
1973	300	54	75	429
1974	300	126	226	652
1975	200	511	280	991
1976	200	261	140	601
1977	<100	29	--	--

¹Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

²Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

³1965-1974 estimated; see text. 1975-76 from FAO (1977).

Table 9.--Estimated mean weights (kg) of tunas and billfishes caught in the Indian Ocean by longliners of Japan and Taiwan.

Year	Albacore	Bigeye tuna	Yellowfin tuna	Blue marlin	Striped marlin	Black marlin	Swordfish	Sailfish
<u>Japan</u>								
1952	18.8	53.4	52.0	67.8	32.8	36.4	--	--
1953	19.2	54.8	48.1	63.8	40.5	37.8	42.4	21.2
1954	19.4	54.8	48.6	63.3	37.7	36.3	49.4	33.3
1955	19.7	32.1	26.3	64.6	37.5	35.5	46.7	23.5
1956	19.9	27.3	29.0	64.7	37.0	35.5	43.8	25.2
1957	20.1	54.1	46.8	65.2	36.1	36.0	36.4	23.9
1958	20.8	55.9	43.7	64.6	36.5	37.6	39.7	28.5
1959	19.8	51.0	39.2	65.4	37.0	37.2	42.5	27.4
1960	19.3	48.5	39.9	64.6	38.0	35.5	38.5	27.3
1961	19.9	49.8	39.7	65.0	36.9	35.5	41.5	26.9
1962	17.5	43.3	36.6	64.7	37.5	37.0	38.8	26.0
1963	17.5	45.3	37.3	64.2	38.5	36.6	38.9	26.2
1964	17.7	48.9	39.9	66.1	36.8	36.5	41.2	26.3
1965	18.1	46.1	33.9	65.2	36.8	35.6	42.5	25.9
1966	17.5	46.1	36.9	65.3	37.0	36.3	40.8	24.2
1967	16.6	43.0	34.6	65.7	36.7	36.2	40.2	24.5
1968	16.2	44.5	28.8	66.0	36.2	35.9	38.2	24.3
1969	14.6	38.5	30.8	66.8	37.1	35.9	37.8	25.1
1970	15.6	39.4	36.3	66.3	37.7	34.6	35.9	27.4
1971	13.9	39.7	27.0	68.1	35.1	38.5	33.0	25.0
1972	13.2	41.3	29.7	64.4	37.7	33.1	38.9	26.6
1973	12.7	39.9	42.9	68.2	34.3	35.8	29.1	29.6
1974	14.4	39.3	37.1	67.1	37.3	36.4	33.1	27.7
1975	14.7	41.2	31.0	67.3	36.0	40.5	34.4	30.0
1976	11.9	39.0	33.5	65.7	35.0	41.7	29.5	31.2
1977 ¹	12.2	41.3	33.5	75.0	38.5	33.3	37.5	--
<u>Taiwan</u>								
1967	15.5	36.4	32.4	75.5	45.3	68.5	42.5	30.1
1968	15.3	34.3	22.2	72.4	40.1	58.0	45.0	26.7
1969	16.9	32.6	27.4	71.9	40.4	61.6	45.8	26.5
1970	17.2	33.3	28.8	69.4	42.5	47.8	40.7	23.3
1971	19.1	33.4	21.0	66.0	39.7	64.0	42.3	25.0
1972	17.5	32.0	26.1	67.1	37.8	61.2	41.9	21.8
1973	14.9	31.4	30.8	69.7	42.3	71.0	45.5	27.2
1974	16.1	34.6	30.5	65.5	42.1	52.3	44.2	24.6
1975	17.5	32.6	26.6	60.3	40.0	49.1	28.8	28.3
1976	15.9	28.3	28.9	31.8	40.8	61.9	45.5	14.6
1977	15.3	31.9	32.0	65.5	41.6	62.2	41.4	26.0

¹1977 average weights for Japan estimated.

Table 10.--Estimated total catch (MT) relative abundance (kg/100 hooks) and effective effort (10^6 hooks) for Indian Ocean albacore, bigeye tuna, and yellowfin tuna.

Year	Albacore			Bigeye tuna			Yellowfin tuna		
	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)
1952	67	21.24	0.32						
1953	1,099	33.56	3.30	3,600	58.62	6.14	13,258	164.33	8.07
1954	2,759	42.52	6.51	7,900	67.06	11.77	24,883	172.62	14.41
1955	3,302	63.84	5.19	6,060	41.85	14.47	27,875	102.12	27.28
1956	4,821	37.46	12.92	8,040	34.92	22.97	38,641	97.93	39.44
1957	4,664	42.36	11.05	12,400	60.19	20.59	36,036	96.09	37.49
1958	6,285	26.29	24.00	11,300	67.37	16.76	25,727	75.44	34.09
1959	10,412	18.63	56.09	8,900	47.15	18.86	24,428	78.74	31.01
1960	11,066	14.78	75.16	15,700	54.71	28.68	40,292	76.44	52.69
1961	15,438	16.48	94.04	13,500	44.81	30.11	34,551	62.19	55.53
1962	17,668	11.60	152.90	19,926	41.92	47.51	55,133	52.20	105.58
1963	12,620	7.37	171.88	14,153	46.63	30.12	29,390	37.32	78.72
1964	18,084	9.56	189.88	18,871	44.75	41.25	30,111	32.30	93.18
1965	12,397	7.11	167.87	20,162	35.81	54.87	34,459	27.33	126.05
1966	17,276	6.26	261.05	26,375	40.34	61.63	56,774	39.74	142.82
1967	23,703	5.74	388.46	27,024	37.38	66.63	44,777	24.04	186.16
1968	17,369	4.55	369.70	38,709	42.38	87.76	88,121	36.21	243.26
1969	21,873	3.42	615.82	34,280	34.06	96.79	62,717	26.87	233.29
1970	15,220	2.90	488.50	34,104	39.23	82.04	42,624	22.23	191.67
1971	10,186	2.02	475.34	22,701	29.99	71.66	43,907	19.91	220.48
1972	11,735	2.46	453.96	18,143	31.56	54.61	40,013	18.04	221.66
1973	22,305	9.23	232.66	14,955	36.15	39.41	40,486	22.69	178.35
1974	28,250	4.44	615.72	26,448	33.69	75.51	36,545	14.14	258.26
1975	11,205	4.55	225.16	38,359	22.71	164.39	43,833	13.82	317.04
1976	14,937	3.87	361.52	28,246	25.12	108.42	39,421	14.54	271.01

Table 11.--Estimated total catch (MT) relative abundance (kg/100 hooks) and effective effort (10⁶ hooks) for Indian Ocean billfishes.

Year	Blue marlin			Striped marlin			Black marlin			Swordfish			Sailfish		
	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10 ⁶ hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10 ⁶ hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10 ⁶ hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10 ⁶ hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10 ⁶ hooks)
1952	800	49.35	1.62	100	5.60	1.78	300	8.99	3.34						
1953	2,000	23.86	8.40	300	4.24	7.10	800	9.17	8.72						
1954	3,300	16.78	19.70	800	5.23	15.32	1,100	10.11	10.87	200	1.38		200	1.90	
1955	3,600	14.21	25.38	780	4.42	17.66	1,080	11.10	9.72	240	2.06		180	1.41	3.90
1956	4,980	10.58	47.17	1,740	3.99	43.72	1,500	7.87	19.06	480	2.00		300	0.97	2.29
1957	3,800	9.09	41.87	1,800	3.36	53.64	1,400	6.29	22.24	300	1.30		300	1.61	1.84
1958	4,100	11.07	37.09	1,700	3.56	47.89	1,200	9.57	12.31	500	1.72	1.47	400	1.90	0.92
1959	4,300	8.94	48.17	2,100	4.26	49.38	1,200	6.83	17.56	500	1.15	2.10	500	3.07	1.84
1960	3,700	6.17	60.06	2,000	2.70	74.19	1,700	5.93	28.64	600	1.36	1.40	500	2.29	2.98
1961	3,200	5.07	63.28	2,400	2.39	100.82	1,400	4.50	31.14	700	1.26	1.33	500	2.63	1.84
1962	3,100	5.08	61.10	1,800	2.24	80.53	1,800	5.17	34.81	900	1.17	1.12	800	2.34	3.90
1963	2,634	3.84	68.63	1,783	2.01	88.93	1,451	4.50	32.27	1,051	1.22	1.40	675	1.70	2.52
1964	3,740	4.32	86.66	1,886	1.85	102.09	1,654	4.23	39.13	1,254	1.10	1.40	777	1.51	1.84
1965	3,878	2.95	131.53	3,335	2.45	136.61	1,344	3.42	39.33	1,344	1.22	1.05	1,222	2.73	3.21
1966	3,754	2.84	132.51	4,163	1.92	216.80	1,391	4.09	34.00	1,391	1.24	1.12	1,296	2.24	3.21
1967	4,074	2.59	157.54	4,463	1.34	334.90	1,548	3.64	42.50	1,831	1.46	1.05	1,972	3.12	3.90
1968	4,036	2.26	178.85	3,436	1.55	226.58	2,460	4.18	58.83	1,971	1.32	0.91	1,630	2.34	2.98
1969	3,875	1.86	208.19	4,729	1.31	361.45	2,339	4.27	54.76	2,284	1.35	1.33	1,187	1.80	3.67
1970	3,038	1.72	177.35	3,110	1.00	313.06	1,845	2.65	69.55	2,255	1.25	1.40	1,016	3.17	3.90
1971	2,532	2.03	124.97	2,092	0.94	222.82	1,435	3.24	44.33	1,583	1.10	1.61	1,349	2.63	3.44
1972	2,509	2.82	89.08	1,511	0.79	191.88	893	1.89	47.29	1,554	1.62	1.96	1,145	2.87	4.36
1973	1,891	3.28	57.69	1,117	1.03	108.48	709	1.93	36.67	1,148	1.05	1.12	429	2.09	5.05
1974	2,370	3.30	71.94	2,800	1.31	214.01	1,342	1.98	67.83	1,771	1.32	0.84	652	2.09	4.59
1975	2,277	1.86	22.33	2,114	1.37	154.43	1,187	1.93	61.39	1,235	1.21	1.19	991	1.51	3.21
1976	1,515	1.88	80.68	3,401	1.92	177.13	476	1.75	27.14	1,069	1.26	1.12	601	2.39	5.28

Table 12.--Results of production model analyses for Indian Ocean albacore, bigeye tuna, and yellowfin tuna.

Smoothing period (yr)	Albacore				Yellowfin tuna				Bigeye tuna			
	$\hat{MSY}$ (MT)	$E_{opt}^{\wedge}$ (10^6 hooks)	$\hat{M}$	Fit index	$\hat{MSY}$ (MT)	$E_{opt}^{\wedge}$ (10^6 hooks)	$\hat{M}$	Fit index	$\hat{MSY}$ (MT)	$E_{opt}^{\wedge}$ (10^6 hooks)	$\hat{M}$	Fit index
1	16,199	86	0.39	0.8065	49,936	∞	0.0	0.9370	59,953	∞	0.0	0.6302
2	17,760	∞	0.0	1.1044	43,058	∞	0.0	1.0138	59,070	∞	0.0	1.0098
3	12,784	∞	0.0	1.0089	45,444	1,455	0.05	1.0019	32,490	452	1.20	1.0024
4	8,864	∞	0.0	1.0025	43,534	∞	0.0	1.0006	30,644	443	0.99	1.0009

Table 13.--Results of production model analyses for Indian Ocean blue marlin, striped marlin, and black marlin.

Smoothing period (yr)	Striped marlin				Blue marlin				Black marlin			
	$\hat{MSY}$ (MT)	$\hat{E}_{opt}$ (10^6 hooks)	$\hat{M}$	Fit index	$\hat{MSY}$ (MT)	$\hat{E}_{opt}$ (10^6 hooks)	$\hat{M}$	Fit index	$\hat{MSY}$ (MT)	$\hat{E}_{opt}$ (10^6 hooks)	$\hat{M}$	Fit index
1	3,215	449	0.10	1.0000	3,572	229	0.05	0.9774	1,526	173	0.75	1.0001
2	2,930	219	0.24	1.0128	3,652	71	0.62	1.0282	1,484	158	0.63	1.0001
3	3,557	∞	0.00	1.0022	3,527	77	0.63	1.0023	1,430	170	0.35	1.0000
4	3,153	607	0.07	1.0008	3,377	78	0.52	1.0008	1,397	217	0.17	1.0000

Table 14.--Percentage distribution of nominal effort (hooks) by Japanese longliners in the Indian Ocean, by latitude, 1952-76.

Year	Latitude																Effort (10 ³ hooks)
	20°-15°N	15°-10°N	10°-5°N	5°N-0°	0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	40°-45°S	45°-50°S			
1952	0.0	0.0	0.0	0.0	28.14	39.34	30.13	2.39	0.0	0.0	0.0	0.0	0.0	0.0		2,974	
1953	0.0	0.0	0.0	0.0	8.96	41.22	42.22	7.60	0.0	0.0	0.0	0.0	0.0	0.0		8,437	
1954	0.0	5.11	11.87	3.56	22.02	26.68	25.35	4.07	1.34	0.0	0.0	0.0	0.0	0.0		13,783	
1955	0.0	0.31	2.65	10.69	34.75	29.60	20.46	0.56	0.89	0.09	0.0	0.0	0.0	0.0		29,626	
1956	0.0	1.06	2.35	9.99	26.01	30.69	26.52	2.92	0.45	0.01	0.0	0.0	0.0	0.0		51,959	
1957	0.53	3.74	8.08	10.90	11.48	27.86	29.17	7.96	0.28	0.0	0.0	0.0	0.0	0.0		28,023	
1958	3.95	7.03	11.48	11.69	9.63	17.19	24.24	7.75	5.72	1.32	0.0	0.0	0.0	0.0		24,573	
1959	1.11	4.28	6.06	10.28	10.78	8.49	13.74	13.91	16.93	14.36	0.06	0.0	0.0	0.0		34,944	
1960	0.02	1.55	3.57	8.73	13.67	12.69	17.95	8.69	7.02	25.47	0.63	0.01	0.0	0.0		54,237	
1961	0.52	1.53	3.73	6.31	8.17	13.80	18.26	12.09	16.17	19.31	0.11	0.0	0.0	0.0		60,027	
1962	0.19	0.46	1.69	7.78	17.24	22.03	13.37	7.60	6.49	17.99	4.98	0.18	0.0	0.0		68,093	
1963	0.24	0.99	2.32	2.54	7.02	17.86	13.23	10.73	8.47	31.22	4.97	0.41	0.0	0.0		57,420	
1964	0.05	0.65	2.30	3.95	6.37	20.59	16.66	7.21	4.40	29.53	7.90	0.39	0.0	0.0		68,872	
1965	0.89	1.35	5.92	11.48	12.18	17.08	11.50	7.14	4.28	21.20	6.03	0.90	0.04	0.01		79,848	
1966	0.18	3.77	6.74	9.40	15.27	17.09	11.84	3.64	4.51	15.76	4.17	0.96	1.80	4.87		89,566	
1967	1.23	3.98	9.20	7.44	8.20	11.19	9.89	4.17	2.19	7.01	10.47	8.14	13.40	3.48		126,305	
1968	0.13	0.65	1.10	5.78	10.08	17.92	9.78	4.77	1.16	3.41	8.53	9.04	15.57	12.08		118,557	
1969	0.78	4.77	6.78	9.68	7.77	5.30	4.81	3.28	1.48	2.74	6.37	20.14	20.92	5.18		101,107	
1970	1.56	2.82	3.55	2.57	4.27	13.51	5.75	4.56	1.22	5.82	7.36	12.98	22.27	11.76		78,170	
1971	0.77	1.17	4.51	4.43	9.35	8.63	2.06	1.79	1.39	3.29	10.54	11.71	19.16	21.20		88,598	
1972	0.48	1.29	10.28	7.95	3.77	5.75	1.93	0.74	0.38	1.06	1.78	12.74	25.95	25.90		72,105	
1973	0.49	0.67	3.68	2.01	2.86	4.00	1.83	1.05	0.60	2.26	2.53	19.73	35.52	22.77		79,326	
1974	0.11	1.32	2.06	3.69	3.91	7.52	4.24	2.21	1.61	2.97	4.19	14.39	33.90	17.88		85,617	
1975	0.35	1.07	2.89	2.68	4.79	8.75	5.90	1.92	1.09	1.79	3.68	16.81	33.71	14.57		91,207	
1976	0.74	0.97	1.72	0.85	1.64	1.77	2.61	0.55	0.48	0.67	1.61	19.23	45.90	21.26		79,914	

LONGLINE STATISTICS BY LOCATION
 FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
 CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

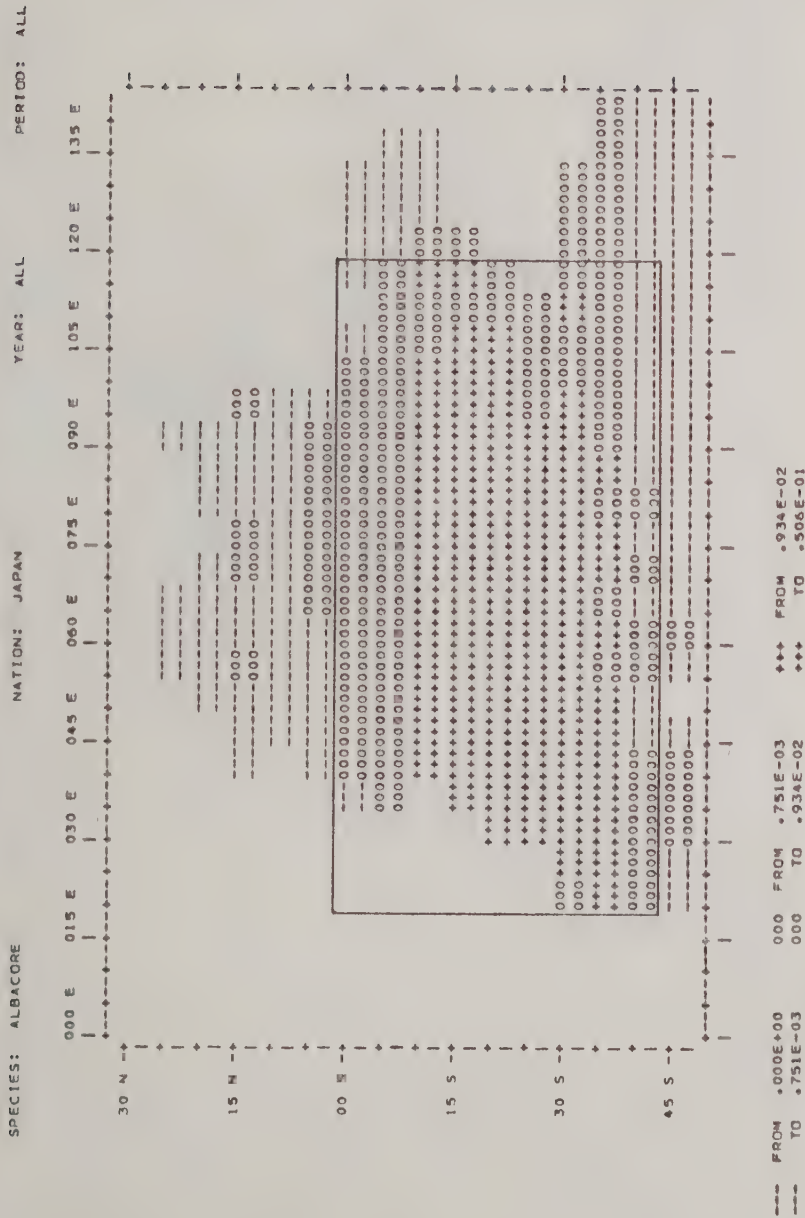


Figure 1.--Distribution of average catch per hook for albacore caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
 FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
 CPUE - AVERAGE OF RATIOS - HOOKS

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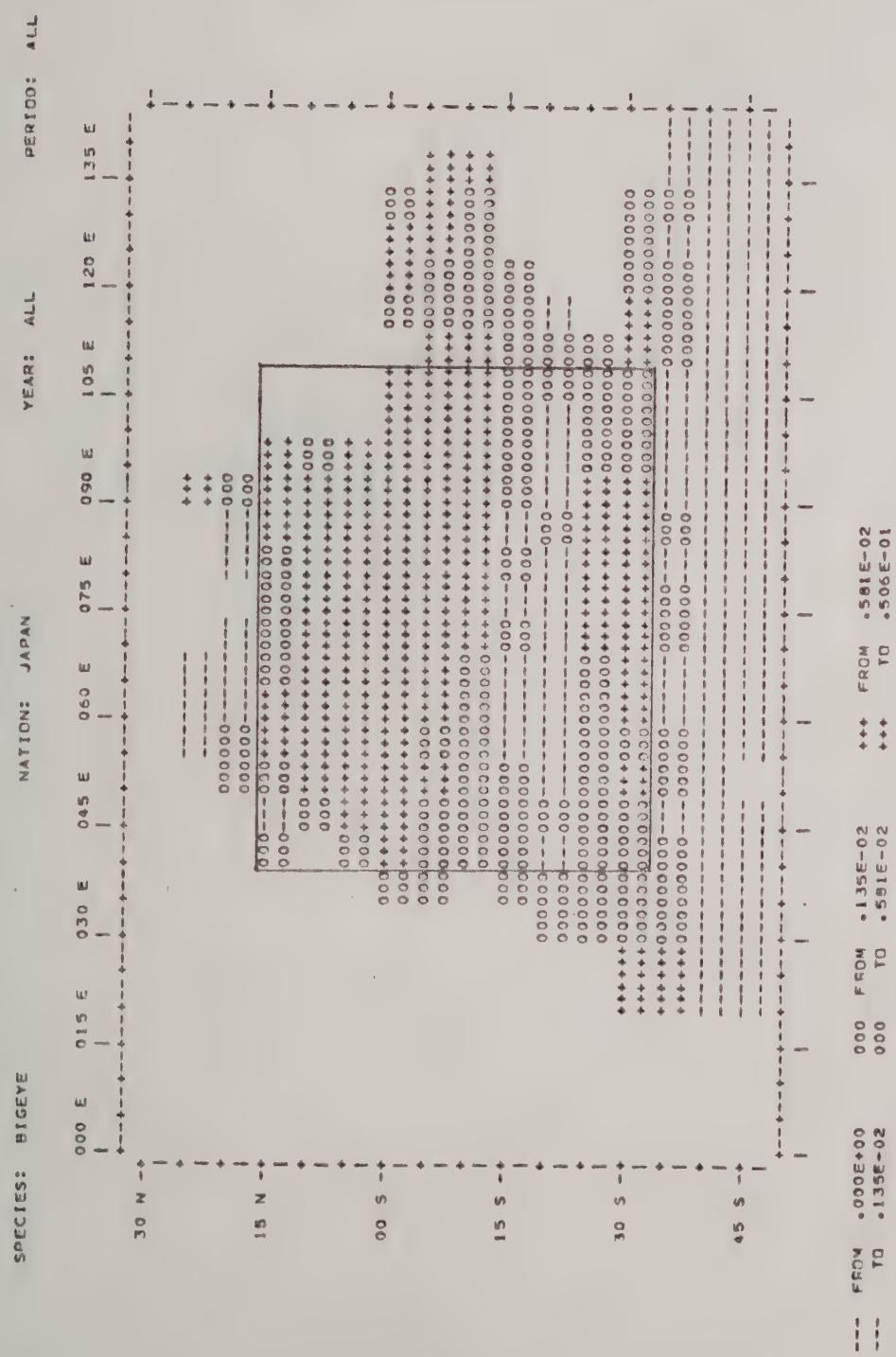


Figure 2.--Distribution of average catch per hook for bigeye tuna caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

CODE 507

SPECIES: BLUE MARLIN NATION: JAPAN YEAR: ALL PERIOD: ALL

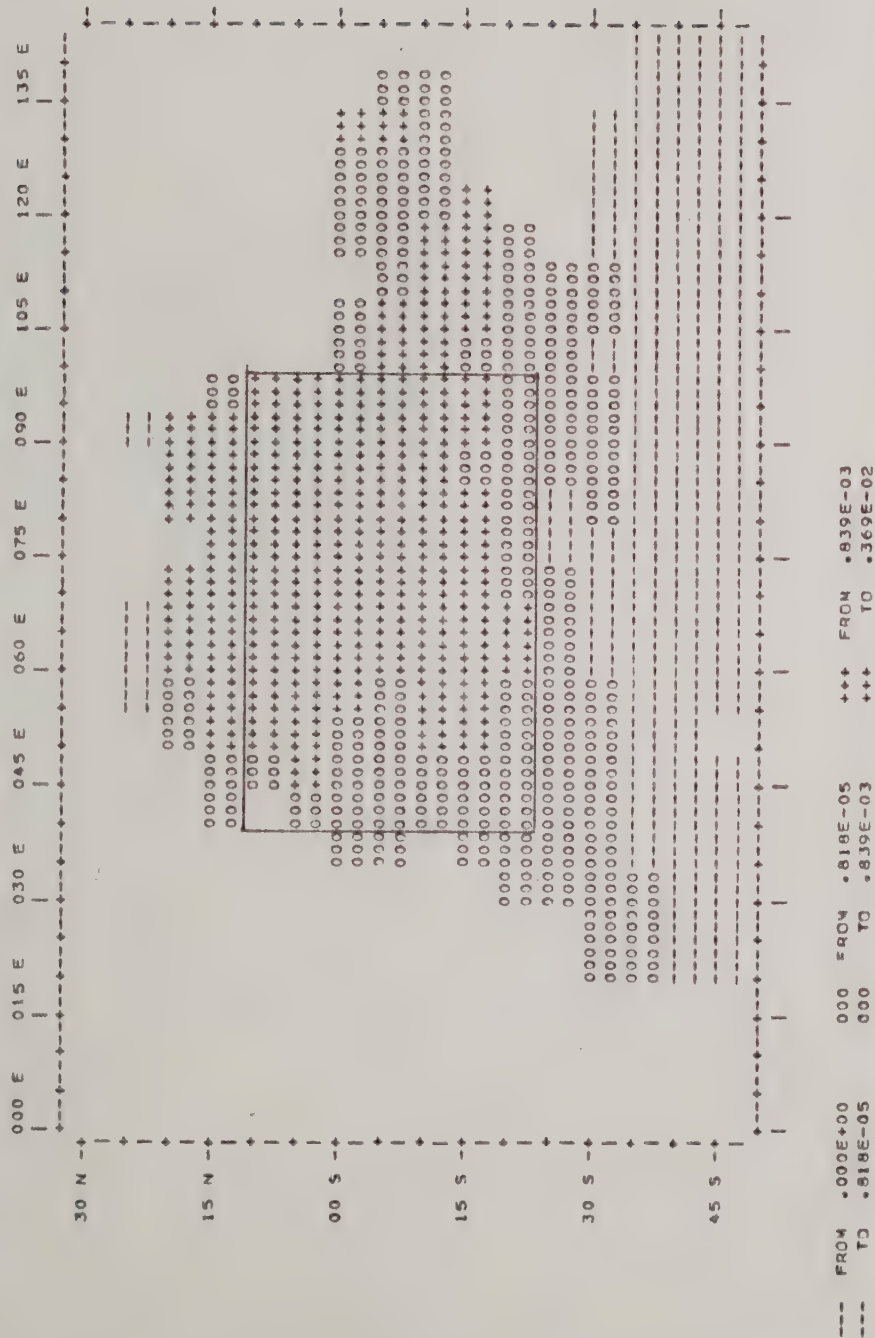
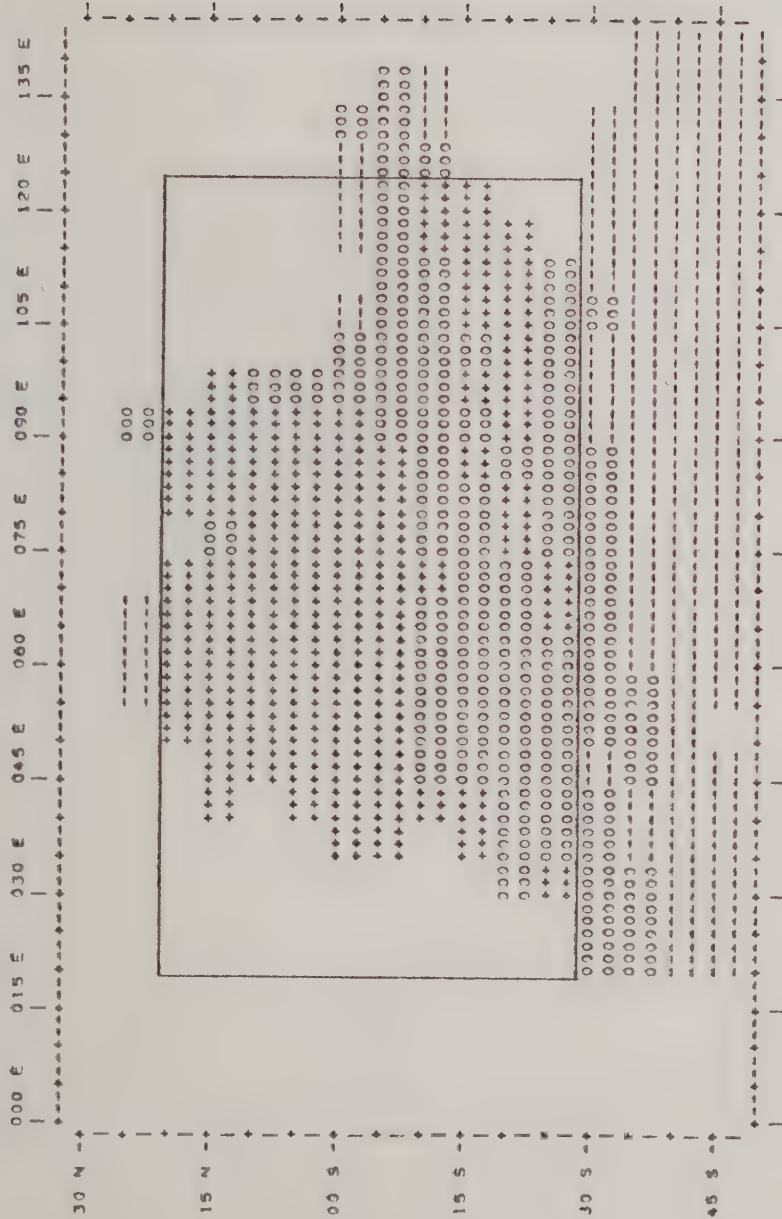


Figure 4.--Distribution of average catch per hook for blue marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
 FAP SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
 CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: STRIPED MARLIN NATION: JAPAN YEAR: ALL PERIOD: ALL



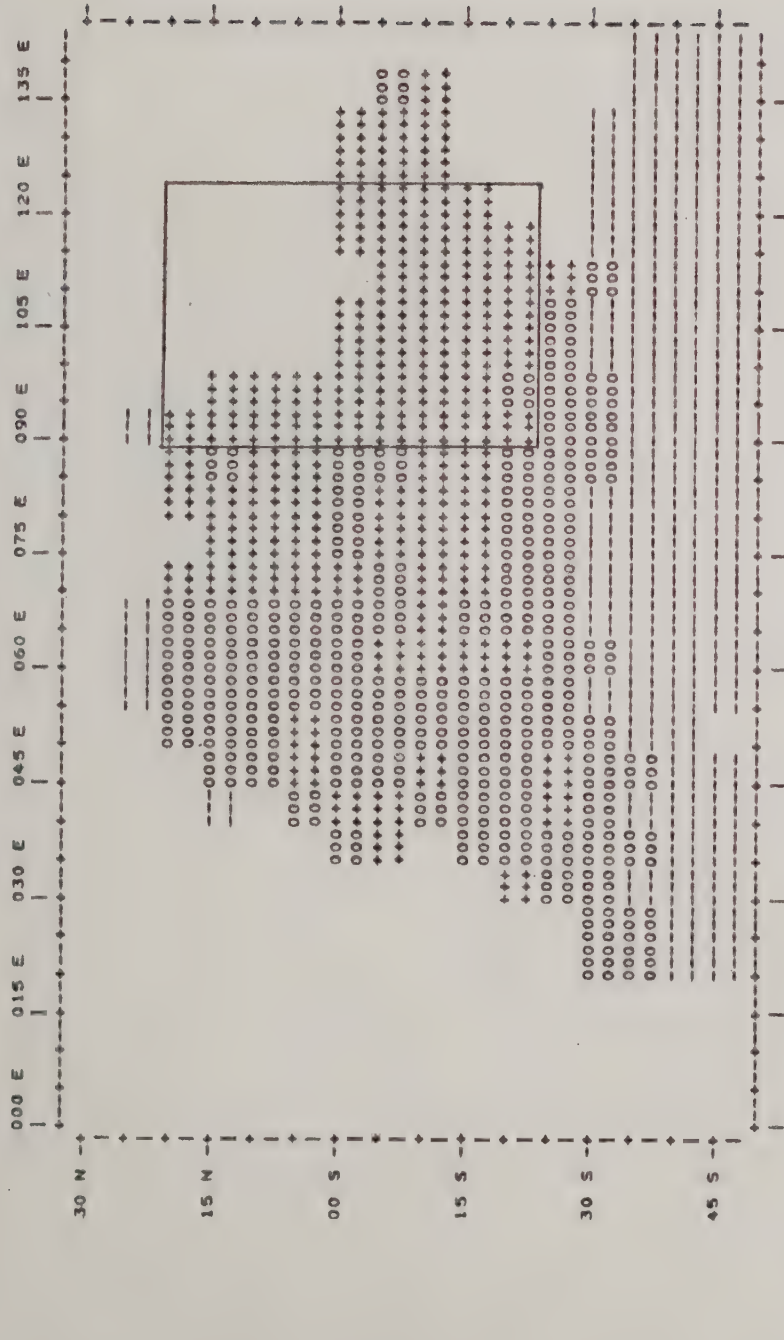
FROM 000E-00 TO 020 FROM 0824E-04 *** FROM 079E-03
 TO 024E-04 TO 079E-03 *** TO 0957E-02

Figure 5.--Distribution of average catch per hook for striped marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
 FAR SEAS FISHERIES RESEARCH LABORATORY DATA (MS5973)
 CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: BLACK MARLIN NATION: JAPAN YEAR: ALL PERIOD: ALL



--- FROM .000E+00 000 FROM .103E-04 *** FROM .367E-03
 --- TO .103E-04 000 TO .367E-03 *** TO .676E-02

Figure 6.--Distribution of average catch per hook for black marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

CODE 807

PERIOD: ALL

YEAR: ALL

NATION: JAPAN

SECRET! SHORFISH

[illegible]

Figure 7.--Distribution of average catch per hook for swordfish caught by Japanese longliners in the Indian Ocean, 1952-76. Index areas outlined.

CODE 507

SPECIES: OTHER GILLFISHES
NATION: JAPAN
YEAR: ALL
PERIOD: ALL

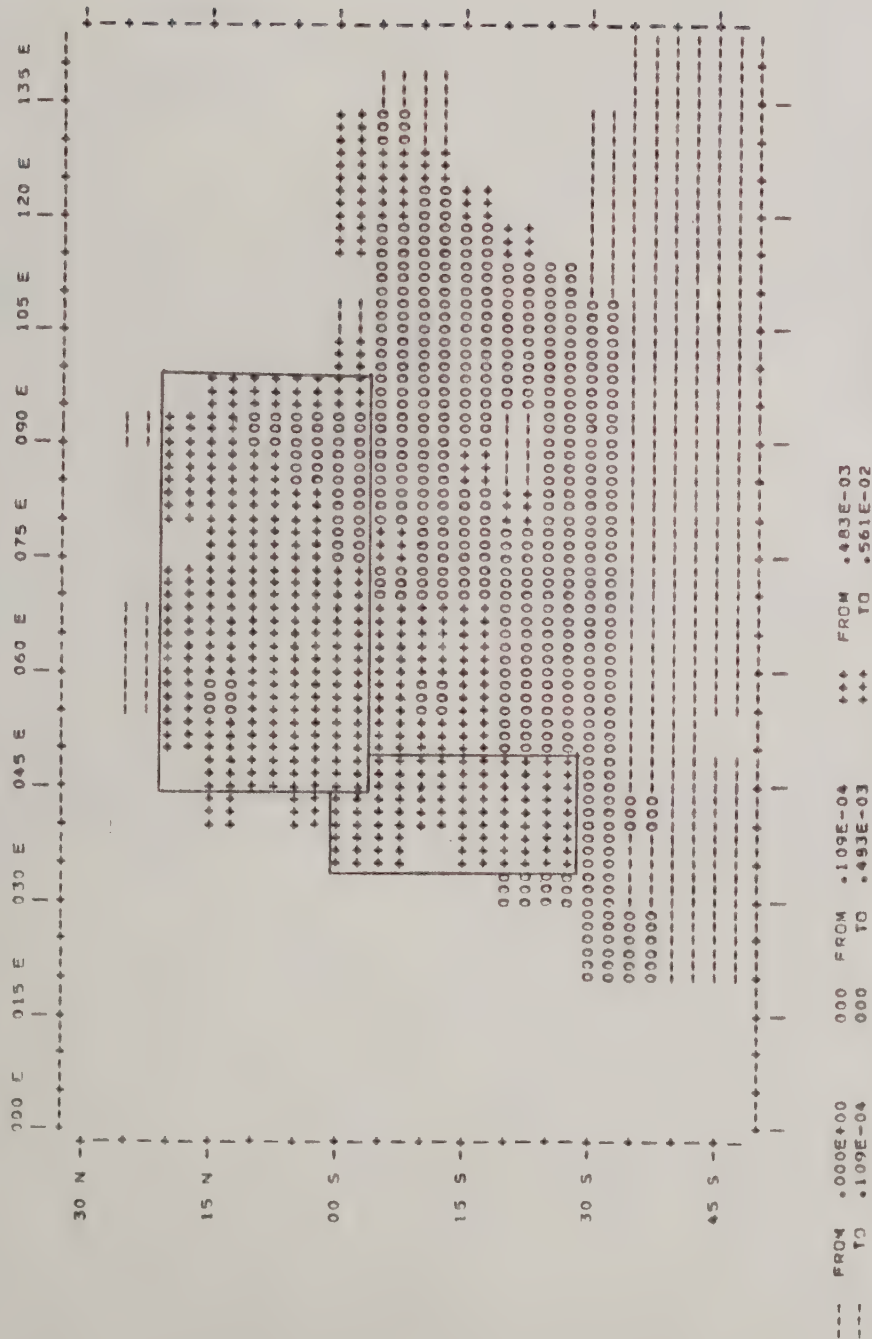


Figure 8.--Distribution of average catch per hook for sailfish caught by Japanese longliners in the Indian Ocean, 1952-76. Index areas outlined.

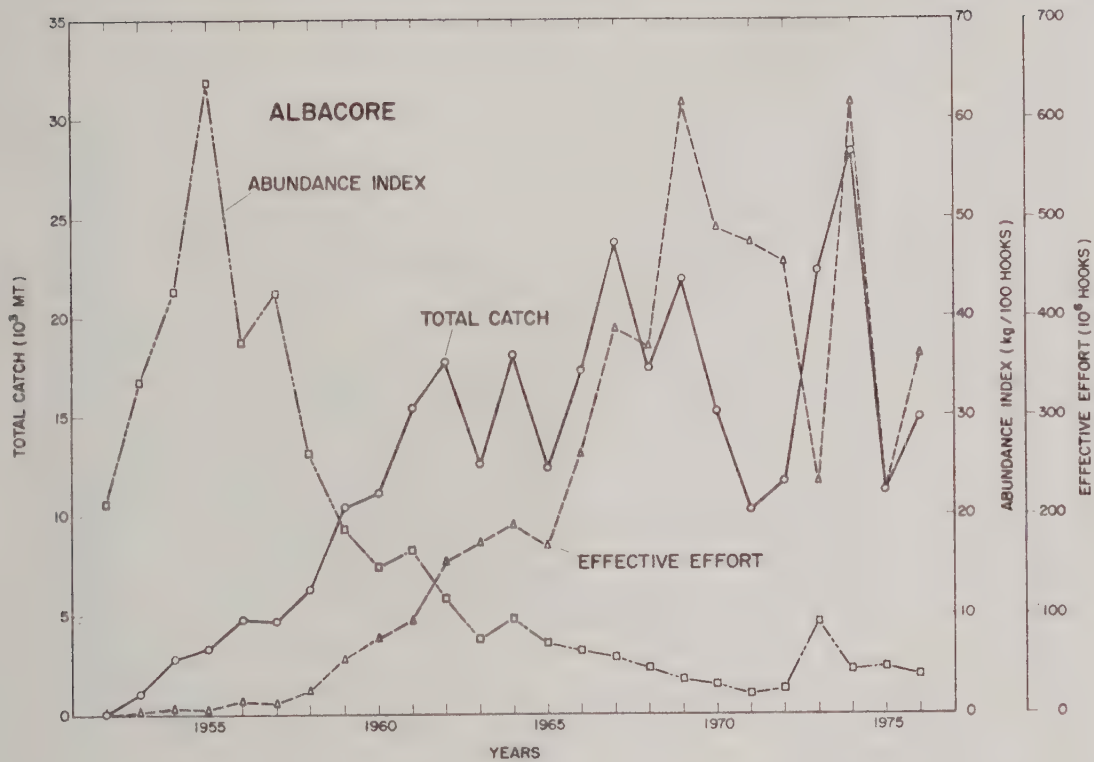


Figure 9.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean albacore.

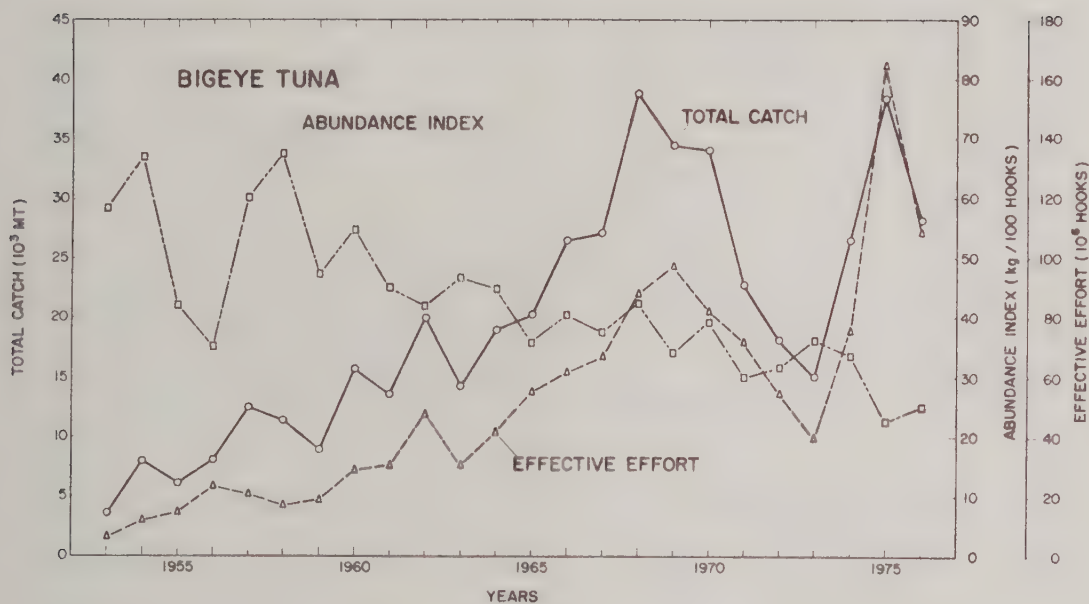


Figure 10.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean bigeye tuna.

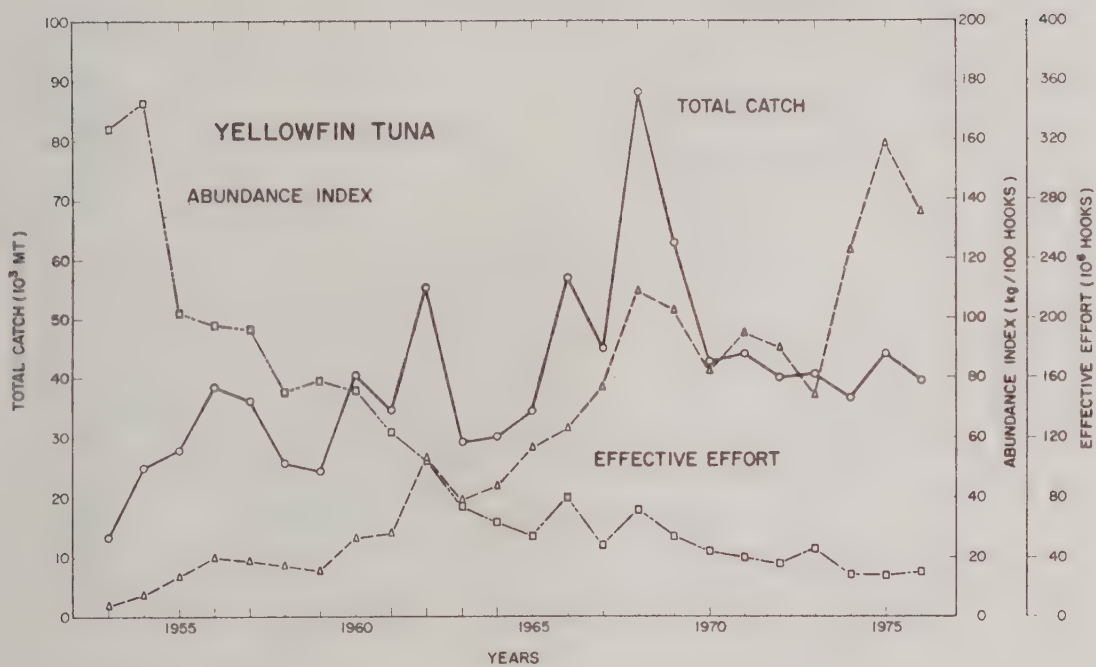


Figure 11.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean yellowfin tuna.

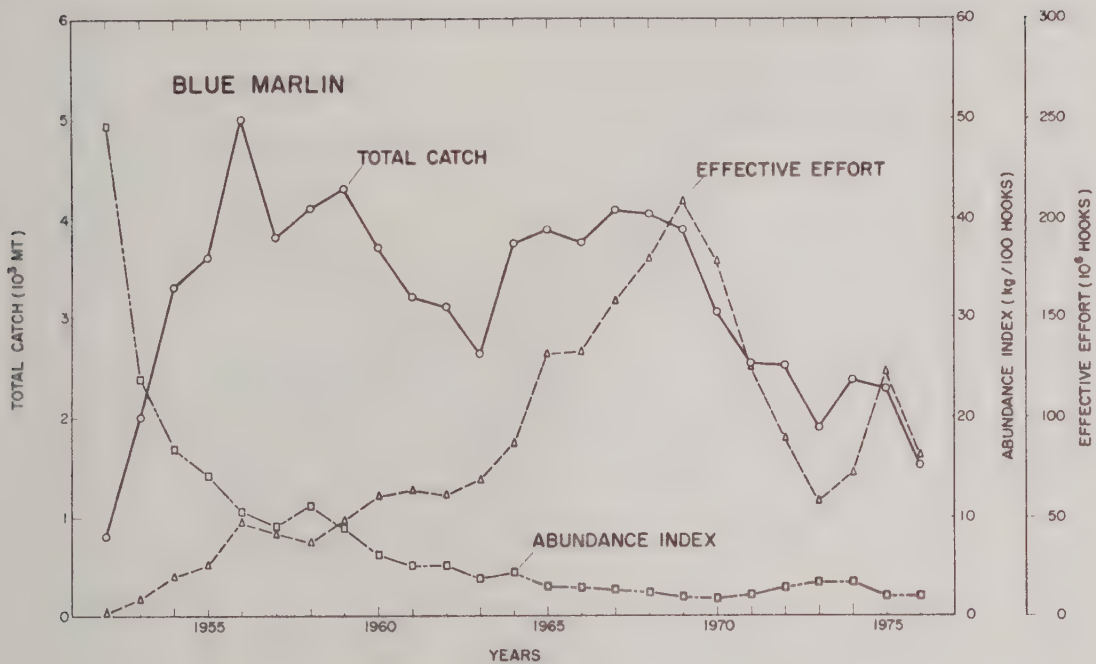


Figure 12.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean blue marlin.

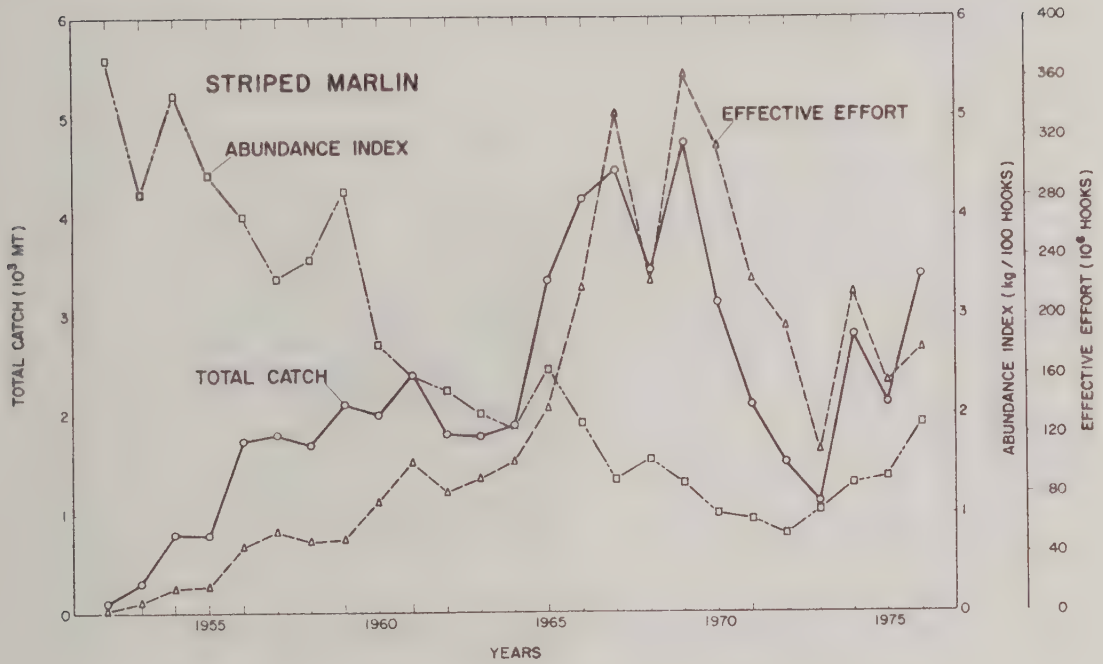


Figure 13.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean striped marlin.

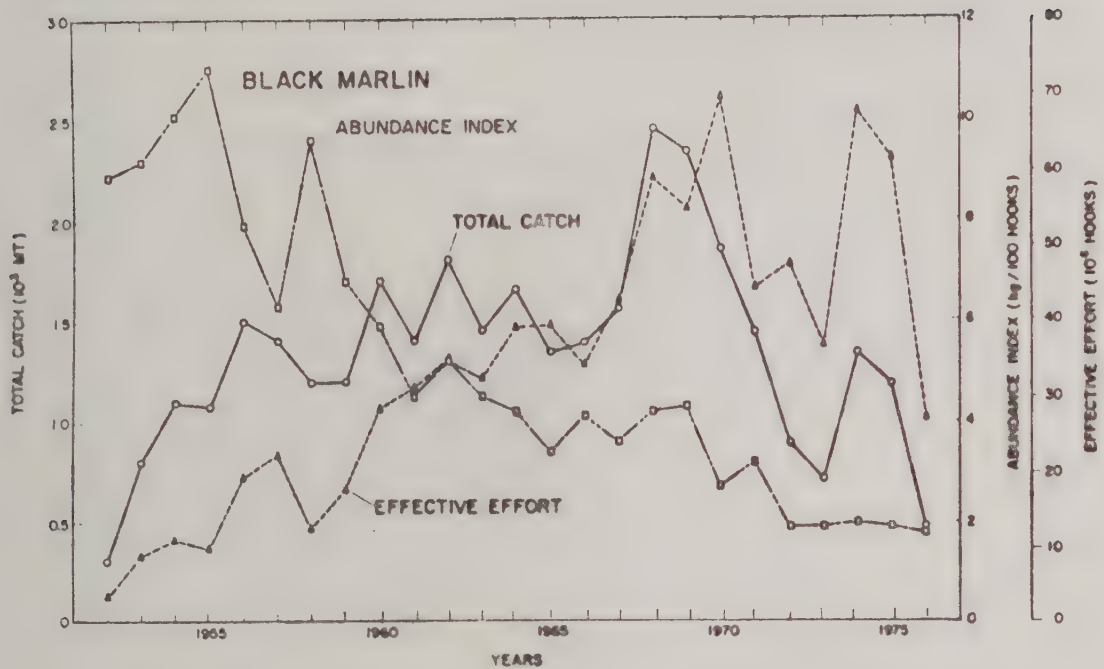


Figure 14.--Estimated total catch (10³ MT), relative abundance (kg/100 hooks), and effective effort (10⁶ hooks) for Indian Ocean black marlin.

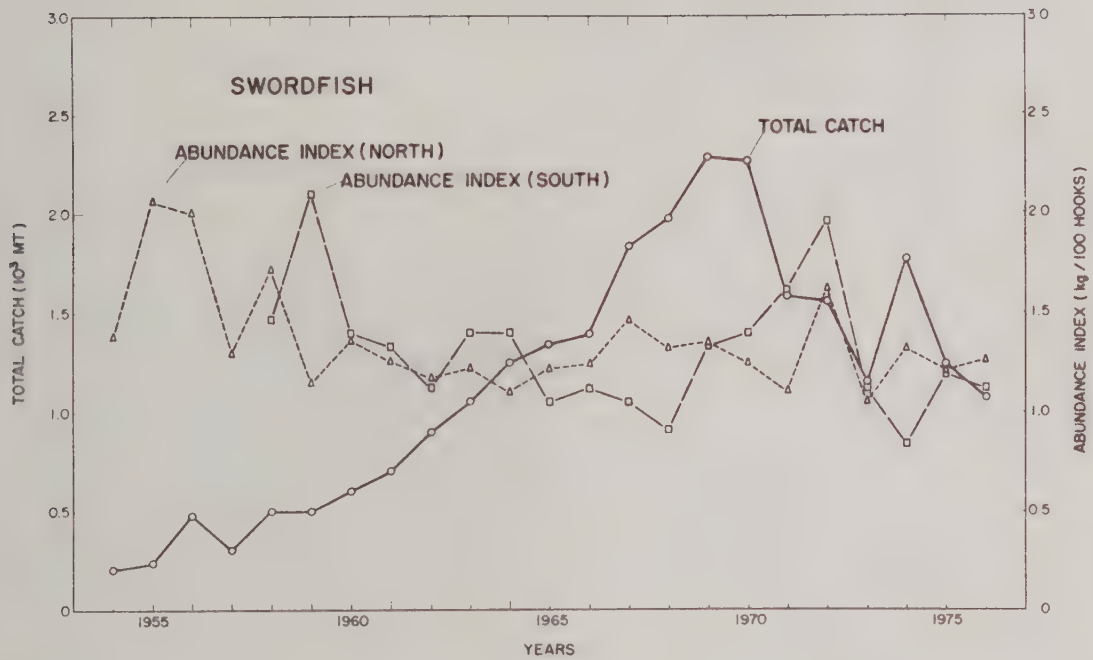


Figure 15.--Estimated total catch (10^3 MT) and relative abundance (kg/100 hooks) for Indian Ocean swordfish. Abundance indices are given for two index areas.

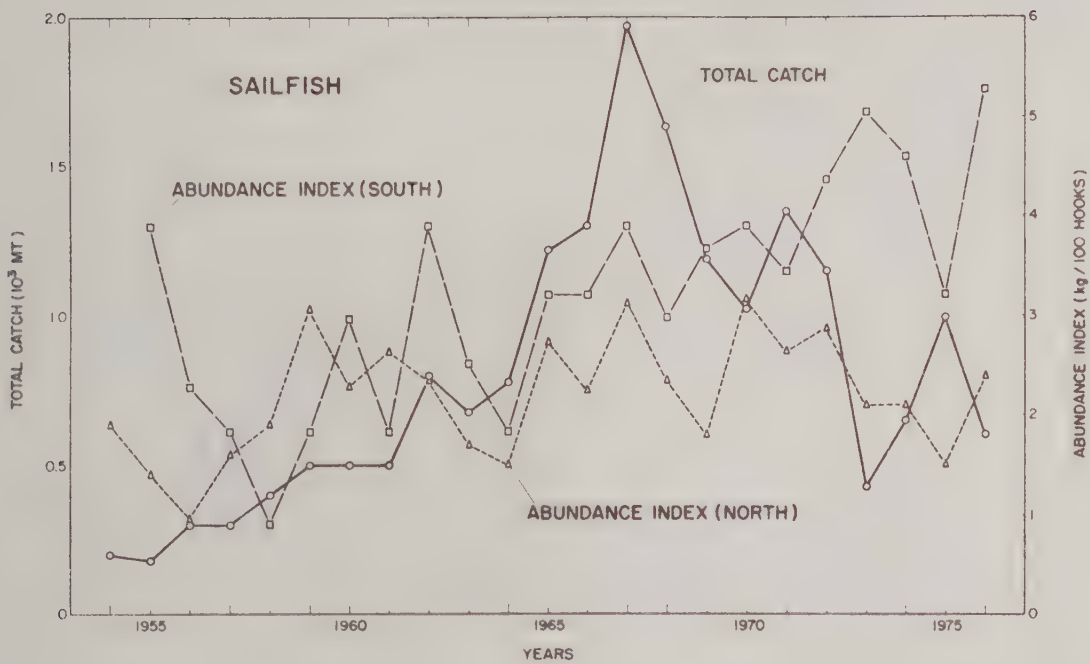


Figure 16.--Estimated total catch (10^3 MT) and relative abundance (kg/100 hooks) for Indian Ocean sailfish. Abundance indices are given for two index areas.

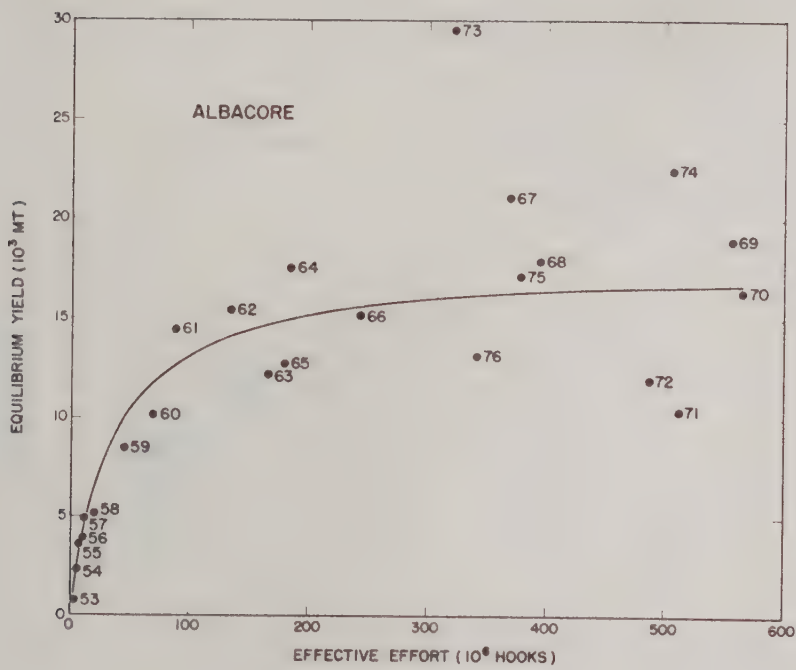


Figure 17.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean albacore, based on production model analysis.

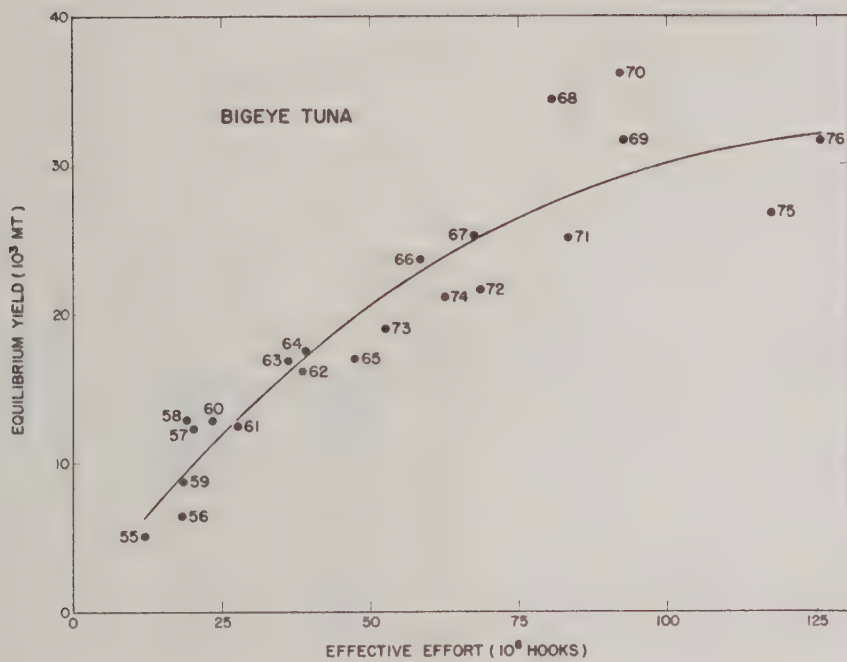


Figure 18.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean bigeye tuna, based on production model analysis.

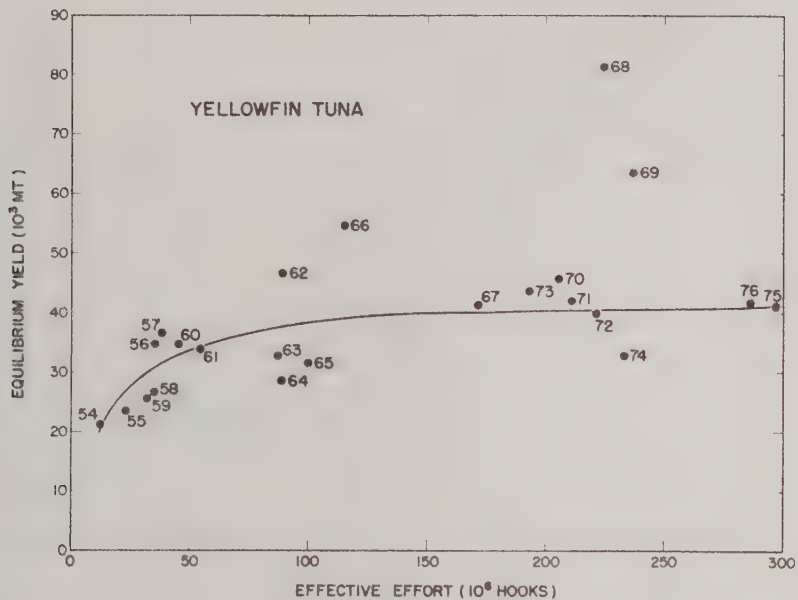


Figure 19.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean yellowfin tuna, based on production model analysis.

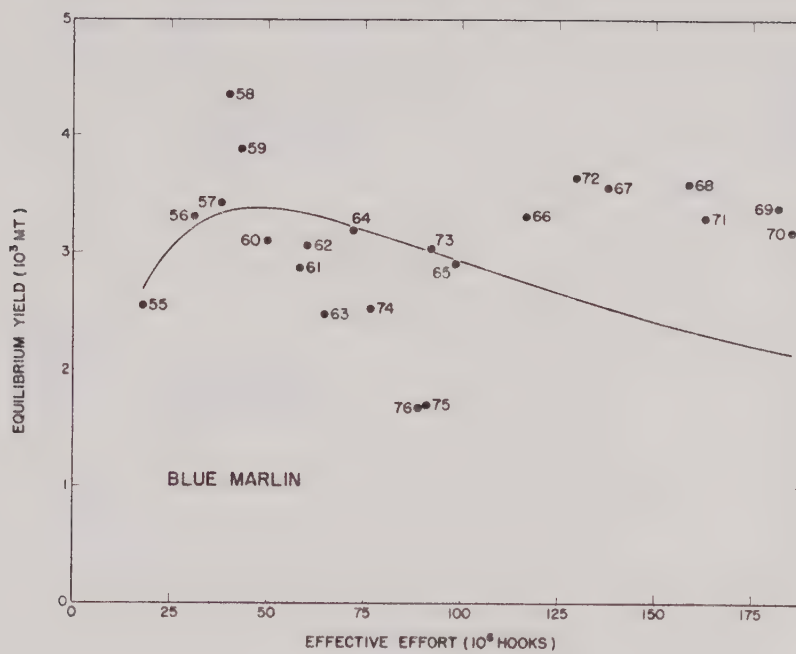


Figure 20.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean blue marlin, based on production model analysis.

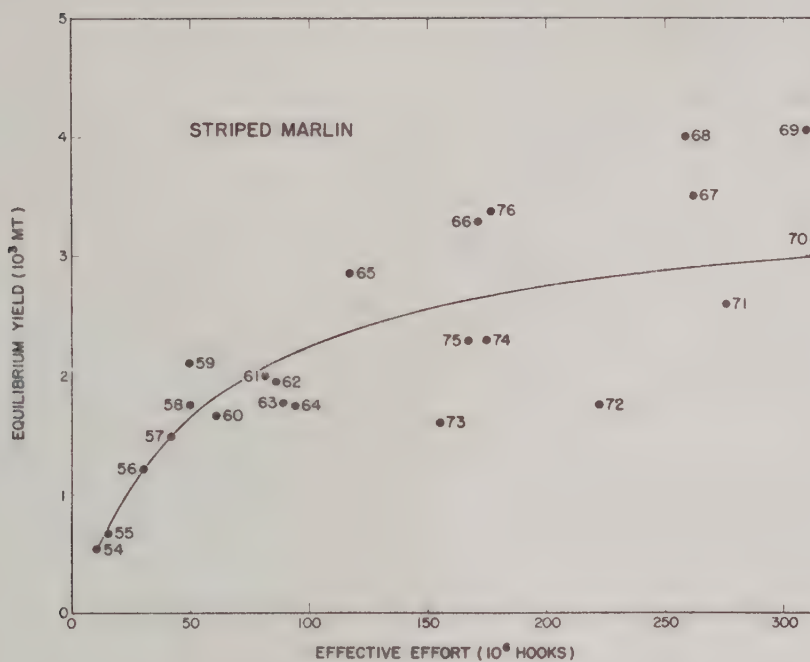


Figure 21.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean striped marlin, based on production model analysis.

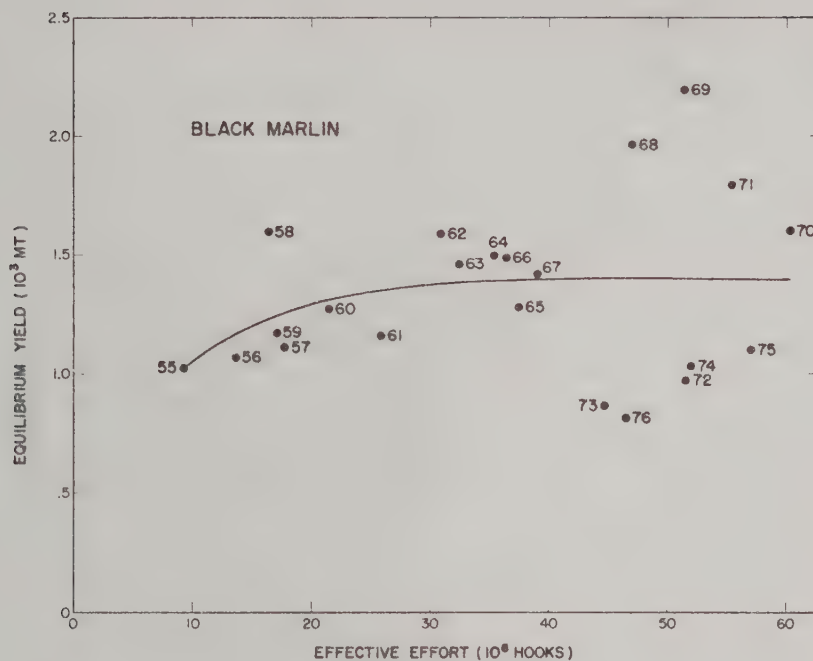


Figure 22.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean black marlin, based on production model analysis.



COMPILATION OF PUBLISHED ESTIMATES OF TUNA LIFE HISTORY
AND POPULATION DYNAMICS PARAMETERS

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This working paper was prepared solely for discussions at the Workshop on the Assessment of Selected Tuna and Billfish Stocks in the Indian and Pacific Oceans (Shimizu, Japan, 13-22 June 1979) and is subject to revision. Its contents should not be cited without consent of the author.

Stock assessment studies require estimates of (1) certain factors that cause changes to the stock and (2) other life history parameters. The purpose of this paper is to compile such data, specifically, published estimates of von Bertalanffy growth parameters, instantaneous mortality coefficients, length-weight relations, fecundity, and size at sexual maturity of tunas including albacore, Thunnus alalunga; bigeye tuna, T. obesus; northern bluefin tuna, T. thynnus; southern bluefin tuna, T. maccoyii; and yellowfin tuna, T. albacares.

Because of the commercial importance of tunas, there is now a large accumulation of information on the biology of these species; however, the data available on each individual species were not equal in volume and information on some species were not as plentiful. Although a rigid set of criteria was not followed in compiling the data, generally, more recent data and those data that appeared "reasonable," in light of available biological information on the various species, were selected for inclusion.

LENGTH-WEIGHT RELATIONS

Numerous length-weight relations of albacore, bigeye, northern bluefin, southern bluefin, and yellowfin tunas in the form, $W = aL^b$, where W is weight in kilograms, L is length in centimeters, and a and b are estimated parameters are available (Tables 1-5). In many of the equations computed by the various authors, the length and weight units used varied. For ease of comparison, all the equations that required it were recomputed in terms of kilograms and centimeters.

Many of the predictive regressions that have traditionally been used to relate length and weight in fishes are in some degree inherently biased (Beauchamp and Olson 1973; Ricker 1973). Ricker (1973) pointed out that a functional regression is more appropriate even for the purpose of prediction and Beauchamp

and Olson (1973) noted that the logarithmic transformation to linearize data used by many investigators introduces an inherent bias. As far as I know all the length-weight relations in Tables 1-5 are uncorrected predictive regressions except that for the South Pacific albacore computed by Yong.¹

VON BERTALANFFY GROWTH PARAMETERS

Estimates of von Bertalanffy growth parameters for the five species of tunas reported on here are numerous in the literature (Tables 6-10). These estimates are available from growth studies based on scale, otolith, and vertebra reading methods, tagging experiments, size-frequency analyses, and varying combinations of the different methods. The growth parameters were either estimated by the original author or by other investigators using data available in the literature (e.g. Shomura 1966).

L_{∞} estimates for albacore (Table 6) range from 104.8 to 146.3 cm. These estimates can be compared to the observed maximum size of albacore, 120-124 cm reported in the literature (Otsu 1960; Miyake and Hayasi 1978). Murphy (1977) stated that L_{∞} is an estimate of the mean maximum size and that "therefore the largest observed fish should be at least slightly larger than the estimated mean maximum size, if the growth equation is to be regarded as realistic." Using this criterion of the reasonableness of the L_{∞} estimates, any estimate greater than about 124 cm for albacore would be unreasonable or unrealistic.

Estimates of L_{∞} for bigeye tuna range from 183.0 to 338.53 cm (Table 7) as compared to observed maximum sizes of 190-198 cm (Shomura 1966; Miyake and Hayasi 1978). For northern bluefin tuna L_{∞} estimates range from 277.3 to 437.46 (Table 8); the observed maximum size is over 300 cm (Miyake and Hayasi 1978). The L_{∞} estimates for southern bluefin tuna are 180.8 to 222.5 cm and the maximum observed size 188 to 230 cm (Murphy 1977; Miyake and Hayasi 1978),

and for yellowfin tuna, 150-307.9 cm (Table 10) and 190 cm (Miyake and Hayasi 1978), respectively.

INSTANTANEOUS MORTALITY COEFFICIENTS

Estimates of instantaneous mortality coefficients (M = natural, F = fishing, Z = total) are available in varying numbers for all the tuna species under consideration (Table 11). It appears that more estimates of mortality rates are available for albacore and yellowfin tuna than for other tunas. However, some available estimates in the literature may have been overlooked.

Murphy and Sakagawa (1977) made a review and evaluation of available estimates of tuna natural mortality rates. The two criteria they used to make their evaluations were (1) how closely the assumptions needed to derive the estimates were met and (2) whether the estimates agreed with other estimates available for the same species. When comparable mortality estimates were unavailable or few, they used the axiom that long-lived species have low natural mortality rates and short-lived species relatively high mortality rates in making their evaluation. They concluded that the most reasonable estimates of M for albacore were between 0.2 and 0.4; for bigeye tuna, in the lower portion of the range 0.35 to 0.73; northern bluefin tuna, 0.1 and 0.2; and yellowfin tuna around 0.8.

FECUNDITY AND SEXUAL MATURITY

Estimates of fecundity are available for all the tunas under consideration (Table 12). However, as far as I could determine, size at first spawning information for northern bluefin and southern bluefin tunas was unavailable in the literature. Baglin (1976) indicated that there still are questions on the actual age of maturity of northern bluefin tuna in the Atlantic.

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TEXT FOOTNOTE

1. M. Y. Y. Yong. Southwest Fisheries Center Honolulu Laboratory,
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commun., May 1979.

Table 1.--Length-weight relations ($W = aL^b$) of albacore. Length (L) is in centimeters and weight (W) in kilograms.

Area	Size range (cm)	a	b	Source	Comments
Eastern Pacific	50.0-85.0	1.225×10^{-5}	3.13	Partlo (1955)	
	38.0-100.0	2.188×10^{-5}	2.99	Clemens (1961)	
Hawaii and North Pacific	49.6-127.6	2.5955×10^{-5}	2.9495	Nakamura and Uchiyama (1966)	
American Samoa (landed)	78.0-108.0	8.8406×10^{-5}	2.6822	Nakamura and Uchiyama (1966)	
North Atlantic	44.0-112.0	6.303×10^{-6}	3.2825	Beardsley (1971)	
South Pacific	--	1.7401×10^{-5}	3.0521	Yong ¹	Males. Functional regression (see Ricker 1973).
	--	1.4168×10^{-5}	3.0967	Yong ¹	Females. Functional regression (see Ricker 1973).
South Africa	--	2.3079×10^{-5}	2.98	de Jaeger (1963)	Males.
	--	1.40343×10^{-5}	3.09	de Jaeger (1963)	Females.
Western North Pacific	45-85	1.781×10^{-5}	3.053	Lee et al. (1978)	

¹See text footnote 1.

Table 2.--Length-weight relations ($W = aL^b$) of bigeye tuna. Length (L) is in centimeters and weight (W) in kilograms.

Area	Size range (cm)	a	b	Source	Comments
Central Pacific	80.0-190.0	3.661×10^{-5}	2.90182	Nakamura and Uchiyama (1966)	
West Africa	41.0-132.0	1.2494×10^{-5}	3.12082	Lenarz (1974)	
South Africa	--	8.24277×10^{-5}	2.72	de Jaeger (1963)	Males.
	--	5.8106×10^{-5}	2.79	de Jaeger (1963)	Females.
Eastern Atlantic (off Ivory Coast)	86.2-179.2	4.454×10^{-5}	3.31768	Choo (1976)	
Western North Pacific	45.5-163.8	1.97308×10^{-5}	3.024669	Morita (1973)	
Central and eastern Pacific	65.5-173.0	1.97927×10^{-5}	3.021632	Morita (1973)	
Atlantic Ocean	50.2-175.5	2.50577×10^{-5}	2.973242	Morita (1973)	
Indian Ocean	73.5-166.5	4.92194×10^{-5}	2.832860	Morita (1973)	

Table 3.---Length-weight relations ($W = aL^b$) of northern bluefin tuna. Length (L) is in centimeters and weight (W) in kilograms.

Area	Size range (cm)	a	b	Source	Comments
Western Atlantic	--	3.17×10^{-5}	2.90444	Sakagawa and Coan (1974)	
Eastern Atlantic	25.0-279.5	1.9×10^{-5}	3.0	Rodríguez-Roda (1964)	May-June 1956-59.
	130.0-249.5	5.3×10^{-5}	2.8	Rodríguez-Roda (1964)	July-August 1956-59.
Eastern Pacific	55.8-178.4	5.686×10^{-5}	2.79012	Bell (1964)	
Western North Pacific	171.0-219.0	2.977×10^{-5}	2.910	Shingu et al. (1974)	
Western South Pacific	171.0-225.0	2.503×10^{-5}	2.9249	Shingu et al. (1974)	

Table 4.---Length-weight relations ($W = aL^b$) of southern bluefin tuna.

Length (L) is in centimeters and weight (W) in kilograms.

Area	Size range (cm)	a	b	Source
Australia	--	3.13087×10^{-5}	2.9058	Robins (1963)
Southeastern Indian Ocean	--	1.01625×10^{-5}	3.115	Shingu (1970)
Southwestern Pacific Ocean	--	9.4624×10^{-6}	3.120	Shingu (1970)

Table 3.---Length-weight relations ($W = aL^b$) of yellowfin tuna. Length (L) is in centimeters and weight (W) in kilograms.

Area	Size range (cm)	a	b	Source	Comments
Pacific coast of Costa Rica	54.2-157.1	2.3864×10^{-5}	2.940	Schaefer (1948)	
Eastern tropical Pacific	47.6-114.9	1.8496×10^{-5}	3.020	Chatwin (1959)	
Hawaii	--	2.8522×10^{-5}	2.9045	Tester and Nakamura (1957)	
Japan	--	6.64×10^{-6}	3.1878	Kamimura and Honma (1959)	Dressed weights of fish used.
Central Pacific	70.0-180.0	1.4769×10^{-5}	3.05834	Nakamura and Uchiyama (1966)	
West Africa	40.0-170.0	2.1804×10^{-5}	2.96989	Lenarz (1974)	
South Africa	--	8.1466×10^{-6}	3.18	de Jaeger (1963)	
	--	3.99165×10^{-5}	2.85	de Jaeger (1963)	
Eastern Atlantic (off Ivory Coast)	104.5-163.0	3.5133×10^{-6}	3.3432	Choo (1976)	
Western South Pacific	26.0-157.0	2.51211×10^{-5}	2.939597	Morita (1973)	
Eastern and central Pacific	63.4-148.0	3.49515×10^{-5}	2.868069	Morita (1973)	
Atlantic Ocean	46.9-169.5	1.6612×10^{-5}	3.026546	Morita (1973)	
Indian Ocean	79.5-162.5	6.5874×10^{-5}	2.750437	Morita (1973)	

Table 6.--Von Bertalanffy growth parameter estimates for albacore. K and t_0 are in years.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_∞ (cm)	K	t_0	
Pacific coast of Japan	Uno (1936)	Vertebra reading	104.8	0.431	1.504	Growth parameters computed by Shomura (1966).
North Pacific	Nose et al. (1957)	Scale reading (1952-53 samples)	114.4	0.308	0.818	Do.
	Nose et al. (1957)	Scale reading (1953-54 samples)	145.3	0.159	-0.056	Do.
	Bell (1962)	Scale reading	108.8	0.2247	-2.2728	Growth parameters computed by author.
Eastern North Pacific; troll	Yabuta and Yukinawa (1963)	Scale reading	146.3	0.150	-0.396	Growth parameters computed by Shomura (1966).
North Pacific; long-line, pole and line, troll	Otsu (1960)	Tagging	118.8	0.250	1.999	Do.
North Pacific; troll, pole and line, rod and reel, longline	Clemens (1961)	Tagging	135.6	0.17	1.87	Growth parameters computed by author.
Atlantic; longline and surface	Beardsley (1971)	Length-frequency analysis	140.0	0.141	-1.63	Do.
Atlantic	Yang (1970)	--	135.0	0.19	--	Do.
North Atlantic; troll	Bard (1974)	Scale reading, length-frequency analysis	134.4	0.183	-0.35	Do.

Table 7.--Von Bertalanffy growth parameter estimates for bigeye tuna. K and t_0 are in years.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_∞ (cm)	K	t_0	
Western North Pacific (north of lat. 25°N, west of 180°)	Yukinawa and Yabuta (1963)	Length-frequency analysis	257.5	0.156	-0.107	Growth parameters computed by Shomura (1966).
Pacific (north of lat. 10°S)	Yukinawa and Yabuta (1963)	Scale reading	215	0.208	0.00055	Growth parameters computed by authors.
	Yukinawa and Yabuta (1963)	Scale reading	213.1	0.212	0.017	Growth parameters computed by Shomura (1966).
Central Pacific (Hawaii); longline	Shomura and Keala (1963)	Length-frequency analysis (males)	196.7	0.267	-0.929	Growth parameters computed by authors.
	Shomura and Keala (1963)	Length-frequency analysis (females)	183.0	0.316	0.718	Do.
Eastern Pacific (east of long. 130°W, lat. 10°N-25°S)	Kume and Joseph (1966)	Length-frequency analysis	186.95	0.38	0.528	Do.
Pacific (north of lat. 10°S)	Nose et al. (1957)	Scale reading	195.2	0.16	-1.128	Growth parameters computed by Shomura (1966).
Eastern Atlantic (Dakar-Pointe-Noire)	Champagnat and Pianet (1974)	Length-frequency analysis	338.53	0.104	-0.542	Growth parameters computed by authors.

Table 8.--Von Bertalanffy growth parameter estimates for northern bluefin tuna. K and t_0 are in years.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_{∞} (cm)	K	t_0	
Southern Spain; traps	Rodríguez-Roda (1971)	Vertebra reading	355.84	0.09	0.89	Growth parameters computed by author.
Western North Atlantic	Mather and Jones ¹	--	447.88	0.053	-1.592	Growth parameters computed by Sakagawa and Coan (1974).
	Butler et al. (1977)	Otolith reading	286.64	0.134	0.3278	Males. Growth parameters computed by authors.
	Butler et al. (1977)	Otolith reading	277.315	0.116	0.7999	Females. Growth parameters computed by authors.
Western North Atlantic; pound nets, hook and line	Mather and Schuck (1960)	Length-frequency scale-vertebra reading	437.46	0.055	-1.489	Growth parameters computed by Sakagawa and Coan (1974).
Western Pacific	Yukinawa and Yabuta (1967)	Scale reading and length-frequency analysis	320.5	0.1035	-0.7034	Growth parameters computed by authors.

¹Mather, F. J. III, and A. C. Jones. 1972. A preliminary review of the stock structure of bluefin tuna in the Atlantic Ocean. Unpubl. manuscr., 18 p. Woods Hole Oceanographic Institution, Woods Hole, MA 02543.

Table 9.--Von Bertalanffy growth parameter estimates for southern bluefin tuna. K and t_0 are in years.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_∞ (cm)	K	t_0	
Southwest Pacific-Southeast Indian Ocean; longline and pole and line	Yukinawa (1970)	Scale reading	219.7	0.135	0.04	Growth parameters computed by author.
South Australia; pole and line	Murphy (1977)	Tagging	180.84	0.146	-0.011	Do.
Australian waters; pole and line and trolling	Shingu (1970)	Length-frequency analysis	222.5	0.14	0.011	Growth parameters computed by author based on data from Robins (1963).
Southwest Pacific-Southeast Indian Ocean; pole and line, trolling, longline	Shingu (1970)	Tagging	187.4	0.149	0.021	Growth parameters computed by author based on Australian and Japanese tagging data.

Table 10.--Von Bertalanffy growth parameter estimates for yellowfin tuna. K and t_0 are in years.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_{∞} (cm)	K	t_0	
Pacific coast of Japan; longline and pole and line	Yabuta and Yukinawa (1957)	Length-frequency analysis	168.9, 168	0.564; 0.55	0.368, 0.35	Growth parameters computed by Shomura (1966) and Suzuki (1971), respectively.
Western Pacific (lat. 12°N-5°S, long. 130°E-180°); longline	Yabuta et al. (1960)	Scale reading	197.5, 190; 188.4	0.312, 0.33, 0.32	-1.030, 0	Growth parameters computed by Shomura (1966), Suzuki (1971), and Le Guen and Sakagawa (1973), respectively.
	Yabuta et al. (1960)	Scale reading	191.1	0.327	-1.020	Growth parameters computed by Shomura (1966) using estimated lengths derived from Walford transformation of scale data.
Central Pacific (Hawaii); mainly longline	Moore (1951)	Weight-frequency analysis	190.2, 192, 191.9	0.454, 0.44, 0.43	0.267, 0.22	Growth parameters computed by Shomura (1966), Suzuki (1971), and Le Guen and Sakagawa (1973), respectively.
Western Pacific (lat. 12°N-5°S, long. 130°E-180°); longline	Yabuta and Yukinawa (1957)	Length-frequency analysis	151.6, 150	0.663, 0.66	-0.620, 0.40	Growth parameters computed by Shomura (1966) and Suzuki (1971).
Eastern Pacific; mainly pole and line	Hennemuth (1961)	Length-frequency analysis (1953-55 year classes)	169, 200.3	0.60, 0.36	0.83, 0.47	Growth parameters computed by author and Le Guen and Sakagawa (1973), respectively.
Eastern Pacific; pole and line and purse seine	Davidoff (1963)	Length-frequency analysis	167, 200.3	0.60, 0.36	0.83	Do.
Eastern Pacific (north of lat. 10°N); pole and line	Diaz (1963)	Extended year class	165.6	0.71	--	Growth parameters computed by author.
	Diaz (1963)	Atelic	214.3	0.36	--	Do.
Eastern Pacific; pole-and-line	Diaz (1963)	Extended year class	167.2	0.65	--	Do.
	Diaz (1963)	Atelic	179.8	0.49	--	Do.
Western Pacific (0° to lat. 10°N, long. 155°-175°E); longline	Yang et al. (1969)	Scale reading	195.2	0.36	--	Do.

Table 10.--Continued.

Area and fishing gear	Investigator(s)	Method	Growth parameters			Comments
			L_{∞} (cm)	K	t_0	
Atlantic (lat. 39.5°N-6°S, long. 83°W-6°E); longline	Yang et al. (1969)	Scale reading	222.8, 223.0	0.28, 0.28	--	Growth parameters computed by author and Le Guen and Sakagawa (1973), respectively.
Eastern Atlantic						
Dakar	Le Guen et al. (1969)	Length-frequency analysis	206.6	0.3144	0.45	Growth parameters computed by authors.
Pointe-Noire	Le Guen et al. (1969)	Length-frequency analysis	182.4	0.4428	0.54	Do.
All areas	Le Guen et al. (1969)	Length-frequency analysis	191.7	0.3828	0.52	Do.
Eastern Atlantic; pole and line and purse seine						
Abidjan	Le Guen and Sakagawa (1973)	Length-frequency analysis (age unknown)	185.0	0.52	--	Do.
Dakar	Le Guen and Sakagawa (1973)	Length-frequency analysis (age unknown)	307.9	0.20	--	Do.
Gulf of Guinea	Le Guen and Sakagawa (1973)	Length-frequency analysis (age unknown)	185.0	0.49	--	Do.
Pointe-Noire	Le Guen and Sakagawa (1973)	Length-frequency analysis (age unknown)	210.1	0.32	--	Do.
All areas	Le Guen and Sakagawa (1973)	Length-frequency analysis (age unknown)	194.3	0.42	0.62	Do.
Eastern Atlantic (São Tomé-Angola); pole and line and purse seine	Le Guen and Sakagawa (1973)	Length-frequency analysis (age known)	175.2	0.53	0.80	Do.
Eastern Atlantic; pole and line	Baudin-Laurencin (1968)	Length-frequency analysis	218.5	0.2952	--	Do.
Eastern Atlantic (Pointe-Noire)	Le Guen and Champagnat (1968)	Length-frequency analysis	165.8, 166.5	0.5568, 0.5418	--	Do.
Eastern Atlantic (Dakar)	Le Guen and Champagnat (1968)	Length-frequency analysis	182.3	0.4308	--	Do.

Table 11.--Estimates of instantaneous mortality coefficients for tunas.

M = natural, F = fishing, and Z = total.

Species	Area	Instantaneous mortality coefficient			Source
		M	F	Z	
Albacore	Atlantic Ocean	0-0.30	--	--	Bard (1974)
	Atlantic Ocean	0.20, 0.32	--	0.96, 0.50, 0.79	Beardsley (1971)
	Pacific Ocean	--	--	0.4	Suda (1963)
	Pacific Ocean	0.2	--	--	Suda (1966)
	South Atlantic Ocean	0.475	--	0.805	Morita (1977)
Bigeye tuna	Indian Ocean	0.4-0.6	--	--	Suda (1974)
	Atlantic Ocean	0.23	--	--	Murphy and Sakagawa (1977)
	Indian Ocean	0.7268	--	1.130	Suda (1970)
Bluefin tuna	Pacific Ocean	0.349, 0.350, 0.5630	--	--	Ishii (1968)
	Pacific Ocean	0.10	--	0.4	Silliman (1966)
	Pacific Ocean	0.361	--	--	Suda and Kume (1967)
	Atlantic Ocean	0.10-0.20	0.28-1.00	0.59-1.75	Mather et al. (1974)
	Atlantic Ocean	0.1-0.2	--	0.48-2.96	Sakagawa and Coan (1974)
	Atlantic Ocean	0.10	--	--	Murphy and Sakagawa (1977)

Table 11.--Continued.

Species	Area	Instantaneous mortality coefficient				Source
		M	F	Z		
Southern bluefin tuna	Indian-Pacific Oceans	0.2	--	--		Murphy (1977)
	Indian-Pacific Oceans	0.2-1.0	0+-2.61	1.15-1.84		Hayasi et al. (1972)
	Indian-Pacific Oceans	0.15, 0.16, 0.18	--	--		Suda (1971)
Yellowfin tuna	Atlantic Ocean	1.58, 2.61	--	--		Pianet and LeHir (1971)
	Pacific Ocean	0.11-4.57	0.56-2.02	0.77-5.17		Fink (1965)
	Pacific Ocean	0.64-0.90	0.82-1.08	1.60-1.85		Hennemuth (1961)
	Pacific Ocean	1.1, 2.5	--	--		Honma et al. (1971)
	Pacific Ocean	0.34, 0.44, 0.91	--	--		Ishii (1969)
	Pacific Ocean	0.55-1.05	0.69-1.20	--		Schaefer (1967)
	Pacific Ocean	0.3-0.8	--	--		Hayasi and Honma (1971)
Indian Ocean		0.35-0.44	--	--		Kawakami and Kitahara (1964) as cited by Suda (1971)
Atlantic Ocean		0.80	--	--		Murphy and Sakagawa (1977)

Table 12.--Estimates of tuna fecundity and size at first spawning.

Species	Area	Size at first spawning	Number of ova per spawning	Source
Albacore	Central Pacific Ocean	90 cm (33 lb)	1-2 million	Otsu and Uchida (1959)
	Central South Pacific Ocean	86 cm	--	Otsu and Hansen (1962)
	Indian Ocean	--	1.8-1.9 million	Ueyanagi (1955)
	Western Pacific	90 cm	0.8-2.6 million	Ueyanagi (1957)
Yellowfin tuna	Central equatorial Pacific Ocean	70 cm	--	Yuen and June (1957)
	Hawaii	--	2-8 million	June (1953)
	Eastern Pacific Ocean	--	0.6-5.5 million	Joseph (1963)
	Eastern Pacific Ocean	50-60 cm	--	Schaefer and Orange (1956)
Bigeye tuna	Pacific Ocean	14-20 kg	2.9-6.3 million	Yuen (1955)
	Western Pacific	90-100 cm	--	Kikawa (1953)
	Indian Ocean	92 cm	--	Kume (1962)
Northern bluefin tuna	Western Atlantic	--	16.7-33.0 million	Baglin (1976)
Southern bluefin tuna	Indian Ocean	--	14.0-15.0 million	Kikawa (1964)

